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ABSTRACT

This module provides instructional materials that are designed to help teachers train students in job skills for entry-level jobs as instrumentation technicians. This text addresses the basics of troubleshooting control loops, and the transducers, transmitters, signal conditioners, control valves, and controllers that enable process systems to work correctly. Pretesting and calibrating instruments are covered, and data charts and calibration graphs that technicians use on a routine basis are provided. The module contains seven instructional units that cover the following topics: principles of pneumatics; calibration standards and test equipment; transducers and transmitters; signal conditioning; actuators, positioners, and control valves; controllers and controller tuning; and interactive loops (boilers, distillation towers, batch processes). Each instructional unit follows a standard format that includes some or all of these eight basic components: performance objectives, suggested activities for teachers and students, information sheets, assignment sheets, job sheets, visual aids, tests, answers to tests, and assignment sheets. Instructional task analyses; a tools, equipment, and materials list; and 21 references are included. (KC)

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Process Instrumentation

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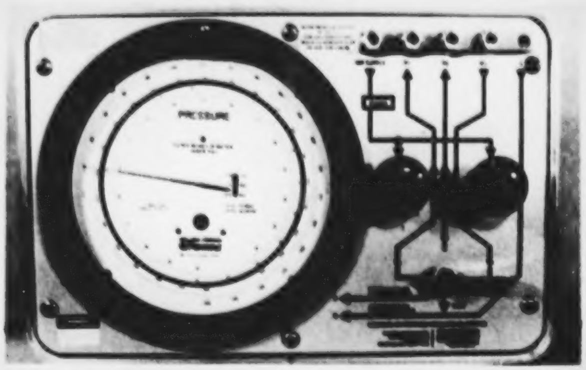

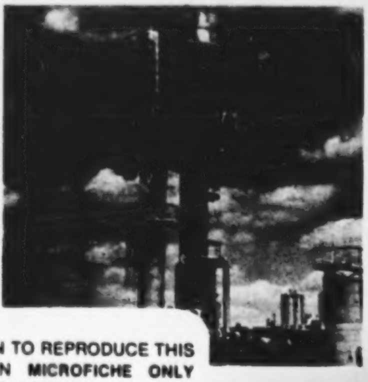

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Teacher Edition

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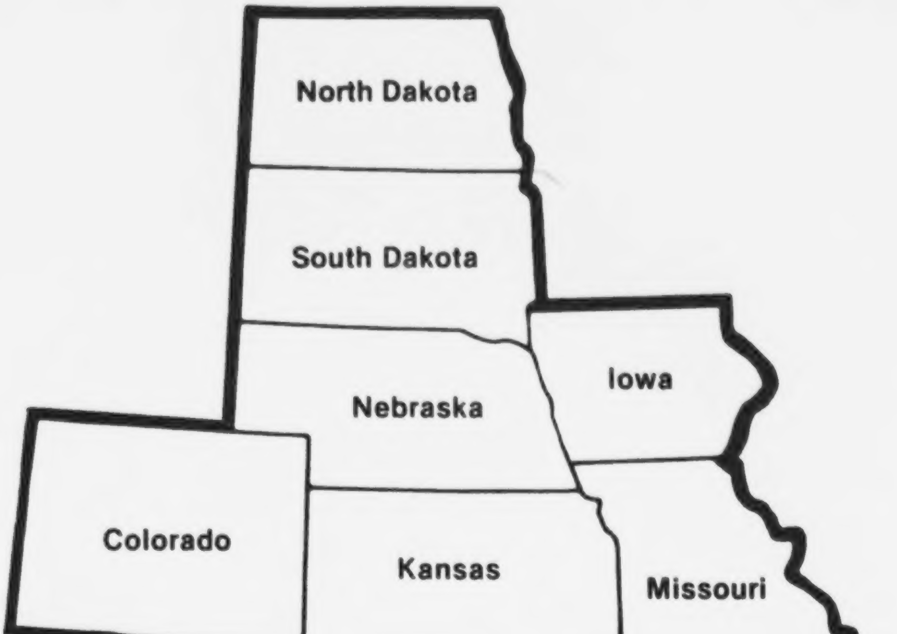
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PROCESS INSTRUMENTATION

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PROCESS INSTRUMENTATION

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FOREWORD

When you buy a liter or gallon of gas, you can bet the gas pump is honest. The pump mechanisms that dispense gas are inspected on regular schedules by a certified technician, and the dated inspection sticker remains on the pump for public inspection. The honest gas pump reflects the heart of process instrumentation — testing, calibration, and record keeping. In a nutshell, that is what process instrumentation is all about. The text addresses the basics of troubleshooting control loops, and the transducers, transmitters, signal conditioners, control valves, and controllers that provide process systems with their brains and brawn.

Pre-testing and calibrating instruments are covered well in the pages that follow, but just as important are the data charts and calibration graphs that a technician deals with on a routine basis. They are all here in a hands-on oriented text that both students and instructors should enjoy.

Instrumentation technicians command excellent pay for what they do, and forecasts indicate that conditions will only get better. To complement this text, we recommend MAVCC's *Introduction to Instrumentation* and MAVCC's *Programmable Controllers*. They join with *Process Instrumentation* to provide a well-rounded curriculum. And just like the honest gas pump — they deliver your money's worth.

Ron Mehrer, Chairman
Board of Directors
Mid-America Vocational
Curriculum Consortium

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Alfred Rardin	The Aviation Education Center, Wichita, Kansas
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We also thank other publishers whose materials have provided reliable reference, and to the instrument distributors and manufacturers whose help with instruction manuals and graphic materials saved us much time and helped provide the authenticity a text like this demands.

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USE OF THIS PUBLICATION

Instructional Units

Process Instrumentation contains nine units of instruction. Each instructional unit includes some or all of the basic components of a unit of instruction; performance objectives, suggested activities for teachers and students, information sheets, assignment sheets, job sheets, visual aids, tests, and answers to the tests. Units are planned for more than one lesson or class period of instruction.

Careful study of each instructional unit by the teacher will help to determine:

A. The amount of material that can be covered in each class period
B. The skills which must be demonstrated

    1. Supplies needed
    2. Equipment needed
    3. Amount of practice needed
    4. Amount of class time needed for demonstrations

C. Supplementary materials such as pamphlets or filmstrips that must be ordered
D. Resource people who must be contacted

Objectives

Each unit of instruction is based on performance objectives. These objectives state the goals of the course, thus providing a sense of direction and accomplishment for the student.

Performance objectives are stated in two forms: unit objectives, stating the subject matter to be covered in a unit of instruction; and specific objectives, stating the student performance necessary to reach the unit objective.

Since the objectives of the unit provide direction for the teaching-learning process, it is important for the teacher and students to have a common understanding of the intent of the objectives. A limited number of performance terms have been used in the objectives for this curriculum to assist in promoting the effectiveness of the communication among all individuals using the materials.

Reading of the objectives by the student should be followed by a class discussion to answer any questions concerning performance requirements for each instructional unit.

Teachers should feel free to add objectives which will fit the material to the needs of the students and community. When teachers add objectives, they should remember to supply the needed information, assignment and/or job sheets, and criterion tests.

Suggested Activities for the Instructor

Each unit of instruction has a suggested activities sheet outlining steps to follow in accomplishing specific objectives. Duties of instructors will vary according to the particular unit; however, for best use of the material they should include the following: provide students with objective sheet, information sheet, assignment sheets, and job sheets; preview filmstrips, make transparencies, and arrange for resource materials and people; discuss unit and specific objectives and information sheet; give test. Teachers are encouraged to use any additional instructional activities and teaching methods to aid students in accomplishing the objectives.

Information Sheets

Information sheets provide content essential for meeting the cognitive (knowledge) objectives in the unit. The teacher will find that the information sheets serve as an excellent guide for presenting the background knowledge necessary to develop the skill specified in the unit objective.

Students should read the information sheets before the information is discussed in class. Students may take additional notes on the information sheets.

Transparency Masters

Transparency masters provide information in a special way. The students may see as well as hear the material being presented, thus reinforcing the learning process. Transparencies may present new information or they may reinforce information presented in the information sheets. They are particularly effective when identification is necessary.

Transparencies should be made and placed in the notebook where they will be immediately available for use. Transparencies direct the class's attention to the topic of discussion. They should be left on the screen only when topics shown are under discussion.

Assignment Sheets

Assignment sheets give direction to study and furnish practice for paper and pencil activities to develop the knowledge which is a necessary prerequisite to skill development. These may be given to the student for completion in class or used for homework assignments. Answer sheets are provided which may be used by the student and/or teacher for checking student progress.

Job Sheets

Job sheets are an important segment of each unit. The instructor should be able to demonstrate the skills outlined in the job sheets. Procedures outlined in the job sheets give direction to the skill being taught and allow both student and teacher to check student progress toward the accomplishment of the skill. Job sheets provide a ready outline for students to follow if they have missed a demonstration. Job sheets also furnish potential employers with a picture of the skills being taught and the performances which might reasonably be expected from a person who has had this training.

Practical Tests

Practical tests provide the instructor with an evaluation instrument for each of the job sheets.

Test and Evaluation

Paper-pencil and performance tests have been constructed to measure student achievement of each objective listed in the unit of instruction. Individual test items may be pulled out and used as a short test to determine student achievement of a particular objective. This kind of testing may be used as a daily quiz and will help the teacher spot difficulties being encountered by students in their efforts to accomplish the unit objective. Test items for objectives added by the teacher should be constructed and added to the test.

Test Answers

Test answers are provided for each unit. These may be used by the teacher and/or student for checking student achievement of the objectives.

PROCESS INSTRUMENTATION

INSTRUCTIONAL TASK ANALYSIS

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)

UNIT I: PRINCIPLES OF PNEUMATICS

JOB TRAINING	RELATED INFORMATION
	1. Terms and definitions
	2. Pneumatic controls
	3. The universal gas law
	4. The law of the conservation of energy
	5. Pascal's principle
	6. The Bernoulli theorum
7. Field service a pressure regulator (Job Sheet #1)	
8. Bench service a pressure regulator (Job Sheet #2)	

UNIT II: CALIBRATION STANDARDS AND TEST EQUIPMENT

JOB TRAINING	RELATED INFORMATION
	1. Terms and definitions
	2. Calibration standards
	3. Standards for length
	4. Standards for mass
	5. Standards for time
	6. Standards for electricity
	7. Standards for temperature
	8. Standards for light
	9. National standards

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)
	10. Primary standards
	11. Secondary standards
	12. Shop or working standards
	13. Manufacturers' specifications
	14. Specifications for accuracy
	15. Specifications for sensitivity
	16. Specifications for repeatibility
	17. Specifications for permanence
	18. Other parameters and applications
	19. Deadweight testers
	20. Manometers
	21. Potentiometers
	22. Frequency meters
	23. Digital VOMs
	24. Decade resistance boxes
	25. Thermal and ice baths
	26. Thermometers
	27. Oscilloscopes
	28. Pneumatic calibrators
	29. Precision power and current supplies
	30. Calibration tools and materials

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

31. Calibrate a test gauge with a pneumatic deadweight tester (Job Sheet #1)
32. Calibrate a test gauge with a hydraulic deadweight tester (Job Sheet #2)

UNIT III: TRANSDUCERS AND TRANSMITTERS

1. Terms and definitions
2. Pressure transducers
3. Steps in the operation of a bourdon tube
4. Spiral and helical bourdon tubes
5. How diaphragms, capsules, and bellows work
6. Piezoelectric crystals
7. Conversion to usable form
8. LVRs and potentiometers
9. LVDTs
10. Variable capacitance/variable frequency systems
11. Mechanical to pneumatic pressure
12. Indicators
13. Pressure transmitters
14. Differential pressure transmitters
15. Calibrating differential pressure transmitters

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

29. Calibrate and test a differential pressure transmitter (Job Sheet #1)

30. Pre-test, calibrate, and post-test a pneumatic pressure transmitter (Job Sheet #2)

31. Field service a temperature transmitter (Job Sheet #3)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

16. Level transmitters

17. Level sensors and their characteristics

18. Calibrating level transmitters

19. Troubleshooting level transmitters

20. Temperature sensors and their characteristics

21. Types of temperature transmitters

22. Calibrating temperature transmitters

23. Flow sensors/transmitters

24. Vortex shedding flowmeters

25. Ultrasonic flowmeters

26. Turbine flowmeters

27. Calibrating vortex and ultrasonic flow units

28. Troubleshooting flow instrumentation

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)
UNIT IV: SIGNAL CONDITIONING	
	1. Terms and definitions
	2. The objectives of signal conditioning
	3. Pneumatic relays
	4. Electrical ratio conditioners
	5. A/D signal conditioning
	6. D/A signal conditioning
	7. Current-to-pressure signal conditioning
	8. Voltage-to-current signal conditioning
	9. Calibrating signal conditioners
	10. Maintenance of signal conditioners
	11. Troubleshooting signal conditioners
12. Calibrate a pneumatic square root extractor (Job Sheet #1)	
13. Calibrate a multi-function computing relay (Job Sheet #2)	
14. Calibrate a current-to-pressure transducer (Job Sheet #3)	
UNIT V: ACTUATORS, POSITIONERS, AND CONTROL VALVES	
	1. Terms and definitions
	2. Parts of a control valve and their functions
	3. Control valve characteristics
	4. Flow characteristics of control valves

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)
	5. Cages
	6. Valve plug guiding
	7. Restricted-capacity valve trim
	8. Valve plugs with groove pins
	9. Packing
	10. Packing lubrication
	11. Control valve types and their characteristics
	12. Other types of control valves
	13. Control valve end connections
	14. Extension bonnets
	15. Guidelines for control valve maintenance
	16. Diaphragm actuators
	17. Electromechanical actuators
	18. Piston actuators
	19. Handwheel and handlever actuators
	20. Valve positioners
	21. Safety in valve/actuator service
	22. Troubleshooting control valve/actuator subsystems
	23. Troubleshooting other final elements
24. Disassemble, inspect, and reassemble a globe-type control valve (Job Sheet #1)	

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

25. Adjust valve plug travel on an actuator (Job Sheet #2)

26. Replace the diaphragm on an air-to-lower actuator (Job Sheet #3)

27. Replace the seat-ring on a globe-type control valve (Job Sheet #4)

UNIT VI: CONTROLLERS AND CONTROLLER TUNING

1. Terms and definitions
2. Open loop control
3. Closed loop control
4. Gain and proportional band
5. Basic controller action
6. Proportional control
7. Integral control
8. Integral time and reset rate
9. Derivative control
10. Dynamics of controller tuning
11. Damping profiles
12. Controller applications
13. Controller tuning basics
14. Basic tuning for flow loops
15. Basic tuning for level loops

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)
	16. Cascade control
	17. Tuning cascaded controllers
	18. Tuning interactive controllers
	19. Feed forward control
	20. Distributed controls
	21. Programmable logic controllers
23. Evaluate controller performance (Assignment Sheet #1)	
24. Tune an electronic controller in an airflow contol loop(Job Sheet #2)	

UNIT VII: INTERACTIVE LOOPS: BOILERS

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)
	1. Terms and definitions
	2. Principles of interaction
	3. Oil combustion control systems
	4. Gas and coal combustion control systems
	5. EPA guidelines for exhaust flue gases
	6. Furnace pressure control
	7. Steam drum control
	8. Steam temperature control
	9. Loop isolation for maintenance
	10. Steps in a blow down procedure
	11. Return to normal operation
12. Identify control functions in interactive boiler loops (Assignment Sheet #1)	

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)	RELATED INFORMATION: What the Worker Should Know (Cognitive)
UNIT VIII: INTERACTIVE LOOPS: DISTILLATION TOWERS	
	1. Terms and definitions
	2. Principles of distillation
	3. Preprocessing
	4. System overview
	5. Heat balance in a distillation tower
	6. Loop isolation for maintenance
	7. Return to normal operations
8. Identify control functions in a distillation tower loop (Assignment Sheet #1)	
UNIT IX: INTERACTIVE LOOPS: BATCH PROCESSES	
	1. Terms and definitions
	2. Fundamentals of batch processing
	3. Batch processes
	4. System overview
	5. Loop isolation for maintenance
	6. Return to normal operations
7. Identify control functions in a typical batch loop process (Assignment Sheet #1)	

PROCESS INSTRUMENTATION

TOOLS, EQUIPMENT, AND MATERIALS LIST

Basic hand tools

Flat blade and Phillips screwdrivers
Combination wrench set
Combination slip-joint pliers
Needlenose pliers
Electricians pliers
Putty knife or gasket scraper
Allen wrench set
Hammer
Packing tool
Seat-ring puller

Materials and equipment

Plastic hose, 30-feet of 1/4"
Quick-connect fittings as required
Needle valves, 2 1/4"
Tape measure
Marker
Pencil
Calculator
Stop watch

Test and measurement instruments

Digital VOM
−1 to 101°C thermometer (F° may be used)
−8 to 32°C thermometer (F° may be used)
0-2000 SCFH rotameter
36" U-tube Mercury manometer
0-150" water pressure gauge (bellows type)
0-15 psi test gauge (Bourdon tube)
0-15 psi pressure gauge (bellows type)
0-1000 psi pressure gauge
Pneumatic deadweight tester
Hydraulic deadweight tester
Pneumatic calibrator
Electropneumatic calibrator
Decade resistance box
Precision power supply

Important!

Safety glasses are required for all performance activities in this text.

Instrumentation

Air pressure regulator
Test gauge
Differential pressure transmitter
Pneumatic pressure transmitter
Temperature transmitter
Pneumatic square root extractor
Multi-function computing relay
Current-to-pressure transducer
Globe-type control valve
Actuator w/travel indicator
Controller
Recorder

PROCESS INSTRUMENTATION

ALPHABETICAL LIST OF REFERENCES USED IN DEVELOPING THIS TEXT

A. *Control Valve Handbook*. Fisher Controls Company. Marshalltown, IA 50158: Fisher Controls Company, 1977.

B. *Dwyer Engineering and Product Applications Handbook*. Michigan City, IN 46360: Dwyer Instruments, Inc., 1986.

C. Gillum, Donald R. *Control Loop Systems*. Austin, TX: Extension Instruction and Materials Center, Division of Continuing Education, The University of Texas at Austin, 1984.

D. Hall, Ronald P. *Automated process Control Systems (Concepts in Hardware)*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1981.

E. *Instruction Book 2096, 11GM Series Pressure Transmitter Styles C and D*. Foxboro, MA: 02035: The Foxboro Company, 1979.

F. *Instructions, Differential Pressure Transmitter 392T, 393T, 394T, 397T, and 398 Model A*. Rochester, NY 14692-0110: Taylor Instrument, a Division of Combustion Engineering.

G. *Instruction, Hi-Flow™ Valve with Lin-E-Aire® Actuator*. 95 Ames Street, Rochester, NY 14601: Taylor Instrument Company, 1981.

H. *Instrumentation Basics, Module C, Instrumentation Test Instruments*. Research Triangle Park, NJ 27709: Instrument Society of America, 1981.

I. *Instrumentation Maintenance, Module 1, Errors in Measuring Instruments*. Research Triangle Park, NJ 27709: Instrument Society of America, 1982.

J. *Instrumentation Maintenance, Module 3, Pneumatic Transducers, Computing Relays*. Research Triangle Park, NC 27709: Instrument Society of America, 1981.

K. Johnson, Curtis D. *Process Control Instrumentation Technology*. New York, NY: John Wiley & Sons, 1982.

L. Jury, Floyd D. Technical monograph 28, *Fundamentals of Three-Mode Controllers*. Marshalltown, IA 50158: Fisher Controls, 1973.

M. Jury, Floyd D. Technical monograph 32, *Fundamentals of Closed Loop Control*. Marshalltown, IA 50158: Fisher Controls, 1975.

N. Liptak, Bela G. *Instrumentation Processing in the Industries*. Philadelphia, PA: Chilton Book Company, 1973.

O. Meier, W.J. *Guide to Controller Tuning*. Ponca City, OK 74602: Engineering Department, Project and Construction Division, CONOCO, 1986.

P. *Pneumatic Instruments*. Research Triangle Park, NC 27709: Instrument Society of America, 1981.

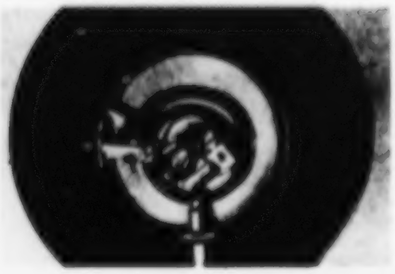
Q. *Process Measurement and Control Terminology, SAMA Standard PMC 20.1-1973*. New York, NY 10017: Process Measurement and Control Section, Inc., Scientific Apparatus Makers Association, 1973.

R. *Service Instructions, Model 40 Nullmatic® Pressure Regulators*. Spring house, PA 19477: Moore Products Co., 1982.

S. *Type 1066 and 1066SR On-Off Piston Rotary Actuators*. Marshalltown, IA 50158: Fisher Controls Company, 1984.

T. *Types 7SA and 7SAR Electromechanical Actuators*. Marshalltown, IA 50158: Fisher Controls Company, 1980.

U. Tyson, Forrest. *Industrial Instrumentation*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1980.



PRINCIPLES OF PNEUMATICS

UNIT I

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss pneumatic concepts and principles used to design pneumatic devices and systems. The student should also be able to field service and bench service a pressure regulator. These competencies will be evidenced by correctly completing the procedures outlined in the job sheets, and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to principles of pneumatics with their correct definitions.
2. Select true statements concerning pneumatic controls.
3. Complete statements concerning the universal gas law.
4. State the law of the conservation of energy.
5. Complete statements concerning Pascal's principle.
6. Apply the Bernoulli theorem to given conditions.
7. Complete statements concerning applications of Pascal's principle.
8. Complete statements concerning applications of Bernoulli's theorem.
9. Demonstrate the ability to:
    a. Field service a pressure regulator. (Job Sheet #1)
    b. Bench service a pressure regulator. (Job Sheet #2)

PRINCIPLES OF PNEUMATICS
UNIT I

SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information sheet.

C. Discuss unit and specific objectives.

D. Discuss information sheet.

E. Demonstrate and discuss the procedures outlined in the job sheets, and review safety requirements for working with solvents and for working around instruments under pressure. Stress the need for wearing safety glasses or appropriate eye protection during field and bench service.

F. Encourage students to open valves slowly when working with test equipment, and explain the dangers of opening valves under pressure too quickly.

CAUTION: Job sheets in this unit and the remainder of this text include procedures designed to demonstrate principles and enhance learning. Under no circumstances should these procedures be used in substitution for in-plant procedures or manufacturers' recommendations.

G. Give test.

REFERENCES USED IN DEVELOPING THIS UNIT

A. Gillum, Donald R. *Control Loop Systems*. Austin, TX: Extension Instruction and Materials Center, Division of continuing Education, The University of Texas at Austin, 1984.

B. Liptak, Bela G. *Instrumentation Processing in the Industries*. Philadelphia, PA: Chilton Book Company, 1973.

PRINCIPLES OF PNEUMATICS
UNIT I

INFORMATION SHEET

I. **Terms and definitions**

   A. Process instrumentation — The application of control equipment for automatically monitoring and making control decisions in industrial processes

   B. Pneumatic — Air or gas operated equipment once very common in industrial controls, and still frequently used where safety or power applications demand

   C. Hydraulic — Liquid fluid operated equipment often used to operate heavy loads such as those found in the actuator part of a control loop

   D. Fluid — A substance such as a liquid or gas that can flow at ambient temperatures

   E. Actuator — A device that operates a control valve

   F. Sensor/transducer — Devices used interchangeably to detect the condition of a variable and convert it to another form compatible with other system components

   G. Controller — A device that operates automatically to receive input, compare input to setpoint, and output information to a final element to regulate a controlled variable

   H. Transmitter — A device that receives low level sensor/transducer output and amplifies the signal to a level suitable for transmission to a device at another location

   I. Field service — Instrument maintenance and repair performed at the point where a device is installed

   J. Bench service — Instrument maintenance, repair, and calibration performed in a service facility

II. **Pneumatic controls**

   A. Pneumatic controls are among the oldest types of controls in process instrumentation.

   B. Pneumatic control devices are dependable, rugged, and require minimal maintenance.

INFORMATION SHEET

C. Where the potential for explosion or fire creates a hazardous environment, pneumatic controls provide a safe control design.

EXAMPLE: Electrical controls around the volatile fluids and gases in a petroleum refinery would create a potential for disaster. That is why petroleum refineries traditionally use pneumatic controls to minimize the potential for loss of life and property.

D. Pneumatic control devices are not the most important form of control devices, but pneumatic controls have traditional applications, and the study of the principles and physical laws of pneumatics is a good place to begin the study of process controls.

III. The universal gas law

A. Gas properties are controlled by three variables:

1. Pressure
2. Volume
3. Temperature

B. The gas law permits a user to determine one variable if the other two variables are known.

C. The gas law also states that if one variable is held constant, the relationship of the other two can be determined.

D. The formula for finding an unknown variable when the two other variables is known is:

For a known mass of gas

$$\frac{P1 \times V1}{T1} = \frac{P2 \times V2}{T2}$$

Where P1 is initial pressure, P2 is resulting pressure

Where V1 is initial volume, V2 is resulting volume

Where T1 is initial temperature, T2 is resulting temperature

INFORMATION SHEET

E. The formula for finding the relationship of two variables when one variable is held constant is:

If pressure is constant, $P1 = P2$

$$\frac{V1}{T1} = \frac{V2}{T2}$$

If volume is constant, $V1 = V2$

$$\frac{P1}{T1} = \frac{P2}{T2}$$

If temperature is constant, $T1 = T2$ $P1 \times V1 = P2 \times V2$

IV. **The law of the conversation of energy**

A. The concepts expressed in the law of the conversation of energy apply to all physical phenomena.

B. The law states: energy cannot be created or destroyed, but it can be transformed from one form to another.

V. **Pascal's principle**

A. A fluid has a property which transmits pressure equally throughout itself, and Pascal's principle expresses it this way: when the pressure in a confined fluid is increased or decreased at any point, the resulting change in pressure is transmitted equally throughout the entire fluid.

(NOTE: Pascal's principle is named for the French physicist and mathematician Blaise Pascal, 1623-1662.)

B. When Pascal's principle is applied to a closed system such as a cylinder, it means that pressure applied to the fluid is transmitted equally to all sides of the container and to the contents.

C. When fluid under pressure is pumped into a cylinder, the piston in the cylinder moves because the piston will move with a force that equals applied pressure and the area of the piston.

VI. **Bernoulli's theorem**

A. Bernoulli's theorem explains the relationship between the velocity of flow and pressure on a liquid or gas in a closed system such as a pipe.

B. The Bernoulli theorem states: an increase in the flow rate of a fluid produces a decrease in pressure, and a decrease in flow rate produces an increase in pressure.

(NOTE: Bernoulli's theorem is named after the Swiss scientist Daniel Bernoulli, 1700-1782.)

INFORMATION SHEET

C. Process controls use three fundamental equations based on Bernoulli's theorem:

1. V = k * sq. rt. (h/d) — The velocity of a fluid, V, is equal to k, a constant for the pipe or vessel, times the square root of the pressure difference across the system, h, divided by the density, d, of the fluid.

   (NOTE: This equation is used to calculate the flow in a pipe using the orifice plate or venturi tube as a primary element.)

2. Q = k * A sq. rt. (h/d) — The volume of flow, Q, is equal to the system constant, k, times A, the cross-sectional area of the pipe, times the square root of the pressure difference, divided by the density of the fluid.

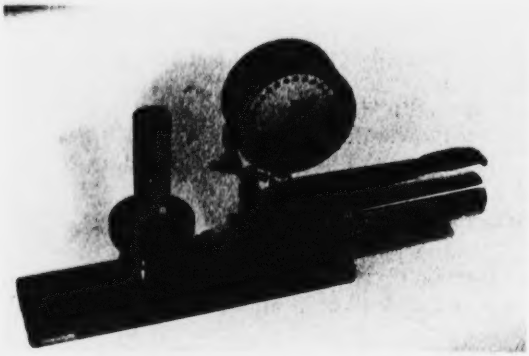
   (NOTE: This equation is used to calculate volume of flow rather than velocity or speed.)

3. W = k * A * sq. rt. (hd) — This equation is used to find mass flow, W, and is similar to the volume flow equation except that the pressure difference, h, is multiplied by the density, d, to find the mass rather than dividing by density to remove the effect of density changes on the flow.

VII. Applications of Pascal's principle

A. Hydraulic and pneumatic deadweight testers use Pascal's principle to calibrate pressure measuring devices. (Figure 1)

FIGURE 1



INFORMATION SHEET

B. A deadweight tester has a platform mounted on a piston with a known cross-sectional area that can be weighted to provide pounds per square inch or kilograms per square centimeter of piston area.

(NOTE: A deadweight tester is a secondary standard traceable to the primary standard at the National Bureau of Standards.)

C. The piston is placed into a fluid-filled vessel that is connected to the gauge under test.

D. When the platform is weighted, the pressure is transmitted through the fluid to the gauge under test.

E. According to Pascal's principle, fluid under pressure will transmit pressure equally in all directions, so the pressure supplied by a known weight (mass) per area square is placed on the gauge being tested, and the gauge reading can be verified against a known pressure.

(NOTE: In a later unit you will have the opportunity to use a deadweight tester in a calibration procedure.)

VIII. Applications of Bernoulli's theorem

A. Bernoulli's theorem is the most commonly used concept in measuring liquid flow.

B. A restriction in the form of an orifice or venturi is placed in a pipe, and the pressure is measured before and after the restriction. (Figure 2)

FIGURE 2

INFORMATION SHEET

C. Since Bernoulli's theorem states that a drop in pressure is directly related to flow velocity, the difference in pressure or differential pressure (ΔP) can be used to infer flow.

PRINCIPLES OF PNEUMATICS
UNIT I

JOB SHEET #1 — FIELD SERVICE A PRESSURE REGULATOR

A. Equipment and materials

1. Safety glasses
2. Pressure regulator (Moore model 40 or equivalent)
3. Basic hand tools
4. Non-abrasive solvent
5. Clean, lint-free shop cloth
6. Pipe cleaners
7. O-ring

B. Routine #1 — Cleaning the restriction screw

1. Put on safety glasses.
2. Turn off air supply.
3. Remove the restriction screw from the bottom forging.

   (NOTE: Refer to Figure 1 that accompanies this job sheet, or to manufacturer's literature as required.)
4. Remove the knurled cleaning wire located near the output port.
5. Run the cleaning wire through the orifice at the tip of the restriction screw.
6. Soak the restriction screw in a non-abrasive cleaner if you have any trouble running the cleaning wire through the orifice tip.
7. Run the cleaning wire through the orifice after solvent cleaning.
8. Examine the O-ring for damage and cleanliness:
   a. If the O-ring is damaged, replace it.
   b. If the O-ring is dirty, clean it with non-abrasive solvent and a lint-free cloth.

   ☐ Have your instructor check your work.

JOB SHEET #1

9. Replace the O-ring.

10. Replace the restriction screw, and tighten it securely.

11. Replace the cleaning wire.

C. Routine #2 — Cleaning the valve plunger

1. Put on safety glasses.

2. Turn off air supply.

3. Remove the retaining nut on the bottom forging, and catch the valve plunger and plunger spring as they drop out as the nut is removed.

4. Use a non-abrasive solvent and a lint-free cloth to clean the valve plunger on both the ball surface and the tapered-end surface.

5. Clean the supply seat with a lint-free cloth, and use solvent, if needed.

7. Inspect all parts for damage.

   ☐ Have your instructor check your work.

8. Reinstall parts in the order they were removed.

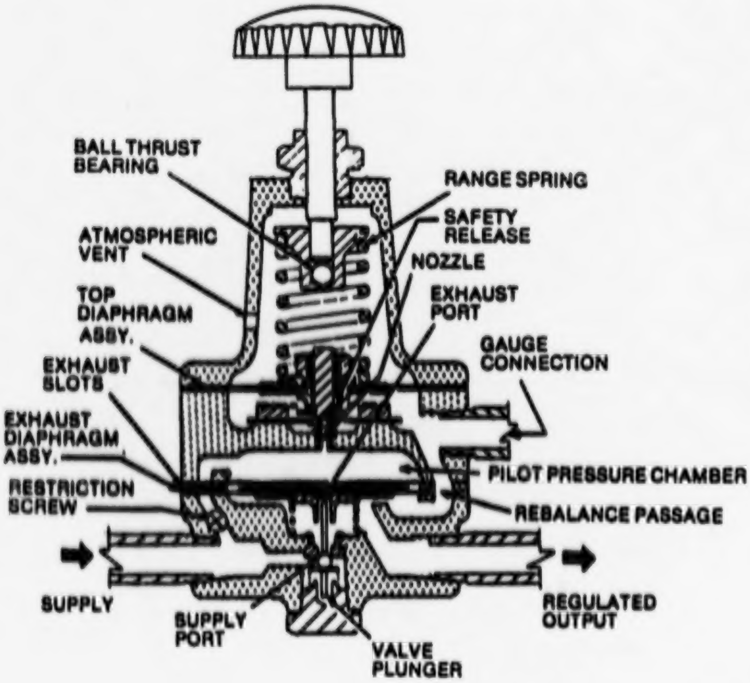
9. Tighten the retaining nut securely.

10. Check the regulator under pressure to verify performance.

11. Clean up area, and return equipment and materials to proper storage.

JOB SHEET #1

FIGURE 1


BALL THRUST BEARING
RANGE SPRING
SAFETY RELEASE
ATMOSPHERIC VENT
NOZZLE
TOP DIAPHRAGM ASSY.
EXHAUST PORT
GAUGE CONNECTION
EXHAUST SLOTS
EXHAUST DIAPHRAGM ASSY.
PILOT PRESSURE CHAMBER
RESTRICTION SCREW
REBALANCE PASSAGE
SUPPLY
SUPPLY PORT
REGULATED OUTPUT
VALVE PLUNGER

Courtesy Moore Products Company

PRINCIPLES OF PNEUMATICS
UNIT I

JOB SHEET #2 — BENCH SERVICE AN AIR PRESSURE REGULATOR

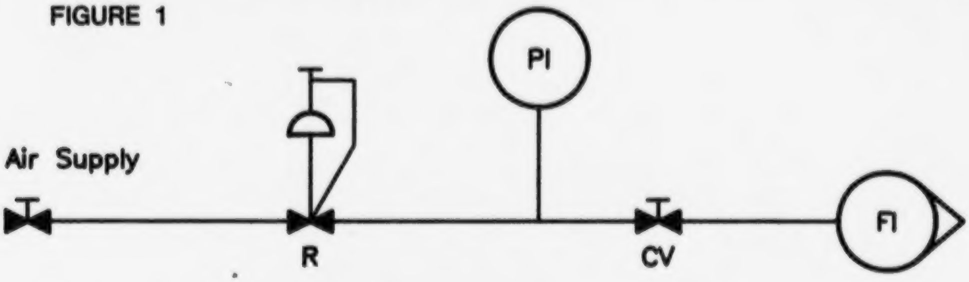
A. Equipment and materials

1. Safety glasses
2. Pressure regulator (Moore model 40 or equivalent)
3. Pressure indicator gauge (P500: 0 to 160 psig or equivalent)
4. Rotameter (Dwyer RMC-121-0 to 10 SCFM or equivalent)
5. Needle valve (Parker 4F-V6LN-4B or equivalent)
6. Bench supply air and valve
7. Basic hand tools
8. Non-abrasive solvent
9. Clean, lint-free shop cloth
10. Marker or crayon
11. Plastic tubing and fittings as required

B. Routine #1 — Pre-testing the pressure regulator

1. Put on safety glasses.
2. Locate instruments in appropriate area near bench supply air, and assemble instruments as indicated in Figure 1.

FIGURE 1



R = Regulator (air pressure)
PI = Pressure Indicator (gauge)
CV= Control valve (needle valve)
FI = Flow Indicator (rotameter)

JOB SHEET #2

3. Make sure all fittings are tight.

4. Close the needle valve (CV).

5. Turn the regulator (R) adjusting knob counterclockwise until it turns freely.

6. Open the bench supply air valve.

7. Turn the regulator (R) adjusting knob clockwise until the gauge (PI) reads 30 psig.

8. Open the needle valve (CV) so that some air flows through the rotameter (FI).

9. Adjust the needle valve (CV), and the regulator (R) until you obtain a reading of 30 psig at 5 SCFM on the rotameter (FI).

10. Reduce the regulator (R) pressure to 10 psig, read the air flow through the rotameter (FI), and record the results:

    ☐ Have your instructor check your readings.

10. Turn bench air off, and remove the air pressure regulator for disassembly.

C. Routine #2 — Disassembling the air pressure regulator

1. Put on safety glasses.

2. Place the regulator in a clean, open area on the work bench.

3. Back off the adjustment knob to relieve spring tension.

4. Make a diagonal mark across all mating parts to assure proper alignment of parts during reassembly.

5. Remove the body screws, and place them in order so you'll remember where to reinstall them.

6. Refer to the manufacturer's literature for order of disassembly.

   (NOTE: If you are working with a Moore model 40, refer to Figure 2 that accompanies this job sheet.)

7. Disassemble parts in order, and make any notes or sketches you feel you might need for reassembly.

8. Keep parts in order on the work bench so that, in general, the last part removed will be the first you replace, and on down the line.

   ☐ Have your instructor check your disassembled regulator.

JOB SHEET #2

D. Routine #3 — Inspecting regulator components

1. Put on safety glasses.

2. Identify the following internal air passages on the regulator, and have your instructor check off each passage you identify correctly:

   ☐ Supply air passage

   ☐ Pilot pressure chamber

   ☐ Rebalance passage

   ☐ Atmosphere vent

   ☐ Output passage

3. Inspect all components for wear and damage.

   (NOTE: Check with your instructor if you have questions about damage or wear that may indicate a replacement component is required.)

4. Write down your general evaluation of the condition of the air pressure regulator components:

   Component evaluation: ____

   ____

   ☐ Have your instructor check your work.

E. Routine #4 — Reassembling the air pressure regulator

1. Put on safety glasses.

2. Position the exhaust diaphragm assembly and exhaust ring so that none of the holes on the bottom forging are blocked.

   (NOTE: Refer to manufacturer's literature, or if you are working with a Moore model 40, refer to Figure 2 that accompanies this job sheet.)

3. Make sure the three external holes on the exhaust ring line up under the gauge connection for proper orientation with respect to the supply and output ports.

4. Position the center housing so that pilot air will flow properly to the bottom cavity of the center housing, and rebalance air to the top cavity.

5. Check manufacturer's graphics (or Figure 2) for orientation of the gauge connection with respect to the supply and output ports.

JOB SHEET #2

6. Install the nozzle seat assembly with the smooth finish seat facing down the nozzle.

7. Position the safety release valve, if the regulator has one, on the nozzle seat assembly before installing the stripper plate.

8. Center the nozzle seat assembly over the nozzle, and them tighten the retaining screws.

9. Put the top diaphragm assembly in place, and then position the top casting so that the nameplate of the casting lines up over the gauge connection.

10. Check all mating parts to be sure that the marks you made during disassembly line up properly.

11. Replace all body screws, and make sure they are tight.

12. Work the adjustment knob slowly back and forth to make sure it has proper action.

    ☐ Have your instructor check your work.

F. Routine #5 — Post-testing the air pressure regulator

1. Put on safety glasses.

2. Locate instruments in an appropriate area near the bench air supply, and assemble the instruments as indicated in Figure 1 of Routine #1.

3. Repeat the pre-test procedure outlined in Routine #1, and record the air flow through the rotameter (FI):

4. Compare your post-test final readings with the final readings from your pre-test:

    a. If the readings are exactly the same, your disassembly and reassembly were correct.

    b. If your readings are different, repeat the post-test again, and compare readings again.

    c. If readings are still different, repeat the disassembly and reassembly procedures, and post-test again.

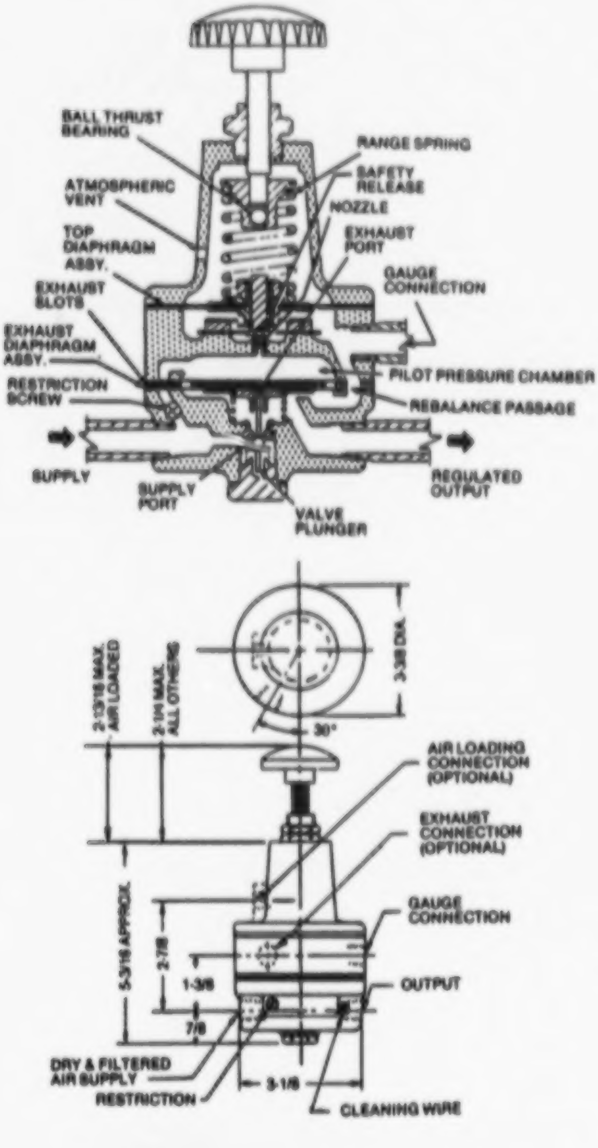
    ☐ Have your instructor check your work.

5. Turn off supply air, and disassemble the testing apparatus.

6. Clean area, and return equipment and materials to proper storage.

JOB SHEET #2

FIGURE 2


BALL THRUST BEARING
RANGE SPRING
SAFETY RELEASE
ATMOSPHERIC VENT
NOZZLE
TOP DIAPHRAGM ASSY.
EXHAUST PORT
GAUGE CONNECTION
EXHAUST SLOTS
EXHAUST DIAPHRAGM ASSY.
PILOT PRESSURE CHAMBER
RESTRICTION SCREW
REBALANCE PASSAGE
SUPPLY
SUPPLY PORT
REGULATED OUTPUT
VALVE PLUNGER
2-13/16 MAX. AIR LOADED
2-1/4 MAX. ALL OTHERS
3-3/8 DIA.
30°
AIR LOADING CONNECTION (OPTIONAL)
EXHAUST CONNECTION (OPTIONAL)
GAUGE CONNECTION
5-3/16 APPROX.
2-7/8
1-3/8
OUTPUT
7/8
DRY & FILTERED AIR SUPPLY
RESTRICTION
3-1/8
CLEANING WIRE

NOTE:
ALL CONNECTIONS ARE 1/4 N.P.T. EXCEPT TAPPED EXHAUST CONNECTION WHICH IS 1/8 N.P.T. WHEN SUPPLIED

Courtesy Moore Products Company

PRINCIPLES OF PNEUMATICS
UNIT I

PRACTICAL TEST #1
JOB SHEET #1 — FIELD SERVICE A PRESSURE REGULATOR

Student's name ______________________________ **Date** ____________

Evaluator's name ______________________________ **Attempt no.** ______

> **Student Instructions:** When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Wore safety glasses.	1.	☐	☐
2. Used cleaning wire.	2.	☐	☐
3. Used solvent safely.	3.	☐	☐
4. Cleaned restriction screw.	4.	☐	☐
5. Cleaned valve plunger.	5.	☐	☐
6. Replaced parts.	6.	☐	☐
7. Post-tested regulator.	7.	☐	☐
8. Returned equipment and materials to proper storage.	8.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #1 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:

Equipment and Materials	Properly selected and properly used 4	Properly selected and acceptably used 3	Poorly selected and/or used 2	Improperly selected and/or used 1
Service Procedure	Well followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1
Post-Testing Equipment	Well completed 4	Acceptably completed 3	Poorly attempted 2	Improperly attempted 1

EVALUATOR'S COMMENTS: ____

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

PRINCIPLES OF PNEUMATICS
UNIT I

PRACTICAL TEST #2
JOB SHEET #2 — BENCH SERVICE A PRESSURE REGULATOR

Student's name ______________________ **Date** __________

Evaluator's name ______________________ **Attempt no.** ______

> Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Wore safety glasses.	1.	☐	☐
2. Completed pre-test.	2.	☐	☐
3. Completed disassembly.	3.	☐	☐
4. Completed component inspection.	4.	☐	☐
5. Completed reassembly.	5.	☐	☐
6. Completed post-test.	6.	☐	☐
7. Returned equipment and materials to proper storage.	7.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #2 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Equipment and Materials	Properly selected and properly used 4	Properly selected and acceptably used 3	Poorly selected and/or used 2	Improperly selected and/or used 1
Pre- and Post-testing Procedures	Well followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Disassembly, Inspection, Reassembly	All properly completed 4	Almost all completed 3	Not adequately completed 2	Not completed 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ______________________________

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

PRINCIPLES OF PNEUMATICS
UNIT I

NAME ______________________________ SCORE ____________

TEST

1. Match the terms on the right with their correct definitions.

______a. The application of control equipment for automatically monitoring and making control decisions in industrial processes

______b. Air or gas operated equipment once very common in industrial controls, and still frequently used where safety or power applications demand

______c. Liquid fluid operated equipment often used to operate heavy loads such as those found in the actuator part of a control loop

______d. A substance such as a liquid or gas that can flow at ambient temperatures

______e. A device that operates a control valve.

______f. Devices used interchangeably to detect the condition of a variable and convert it to another form compatible with other system components

______g. A device that operates automatically to receive input, compare input to setpoint, and output information to a final element to regulator a controlled variable

______h. A device that receives low level sensor/transducer output and amplifies the signal to a level suitable for transmission to a device at another location

______i. Instrument maintenance and repair performed at the point where a device is installed

______j. Instrument maintenance, repair, and calibration performed on in a service facility

1. Transmitter
2. Hydraulic
3. Bench service
4. Process instrumentation
5. Field service
6. Fluid
7. Pneumatic
8. Controller
9. Actuator
10. Sensor/transducer

TEST

2. Select true statements concerning pneumatic controls by placing an "X" beside each statement that is true.

_____a. Pneumatic controls are among the oldest types of controls in process instrumentation.

_____a. Pneumatic control devices are dependable, rugged, and require minimal maintenance

_____a. Where the potential for explosion or fire creates a hazardous environment, pneumatic controls provide a safe control design.

_____a. Pneumatic control devices are the most important form of control devices.

3. Complete statements concerning the universal gas law by circling the material that best completes each statement.

a. Gas properties are controlled by three variables:

1) **(Pressure, velocity)**

2) **(Volume, rate)**

3) **(Temperature, force)**

b. The gas law permits a user to determine one variable if **(the other two variables are known, only one other variable is known).**

c. The gas law also states that if one variable is held constant, **(the relationship of the other two can be determined, the status of one other relationship can be determined).**

d. The formula for finding an unknown variable when the two other variables is known is:

For a known mass of gas

$$\frac{P1 \times V1}{T1} = \frac{P2 \times V2}{T2}$$

Where P1 is **(initial, resulting)** pressure, P2 is **(resulting, initial)** pressure

Where V1 is **(initial, resulting)** volume, V2 is **(resulting, initial)** volume

Where T1 is **(initial, resulting)** temperature, T2 is **(resulting, initial)** temperature

TEST

4. State the law of the conversation of energy.

   Answer: ____

   ____

5. Complete statements concerning Pascal's principle by circling the material that best completes each statement.

   a. A fluid has a property which transmits pressure equally throughout itself, and Pascal's principle expresses it this way: when the pressure in a confined fluid is increased or decreased at any point, the resulting change in pressure is transmitted (**equally, only partially**) throughout the entire fluid.

   b. When Pascal's principle is applied to a closed system such as a cylinder, it means that pressure applied to the fluid is transmitted equally to all sides of the container and to the (**contents, top**).

   c. When fluid under pressure is pumped into a cylinder, the piston in the cylinder moves because the piston is free to move, but pressure on the walls of the cylinder (**cannot cause a change, cause an equal change**).

6. a. The flow rate in a pipe increases; what will happen to the pressure in the pipe?

   Answer: ____

   b. The flow rate in a pipe decreases; what will happen to the pressure in the pipe?

   Answer: ____

7. Complete statements concerning applications of Pascal's principle by circling the material that best completes each statement.

   a. A device called a deadweight tester uses Pascal's principle to (**calibrate, evaluate**) pressure measuring devices.

   b. A deadweight tester has a platform mounted on a piston with a known cross-sectional area that can be weighted to provide pounds per square inch or kilograms per (**square centimeter, square inch**) of piston area.

   c. The piston is placed into a (**fluid-filled, hydraulic chamber**) vessel that is connected to the gauge under test.

   d. When the platform is weighted, the pressure is transmitted through the (**fluid, chamber**) to the gauge under test.

   e. According to Pascal's principle, fluid under pressure will transmit pressure equally in all directions, so the pressure supplied by a known weight per area square is placed on the gauge being tested, and the gauge reading can be verified against (**a known pressure, an equivalent weight**).

TEST

e. According to Pascal's principle, fluid under pressure will transmit pressure equally in all directions, so the pressure supplied by a known weight per area square is placed on the gauge being tested, and the gauge reading can be verified against (**a known pressure, an equivalent weight**).

8. Complete statements concerning applications of Bernoulli's theorem by circling the material that best completes each statement.

   a. Bernoulli's theorem is the most commonly used concept in measuring (**liquid flow, pressure**).

   b. A restriction in the form of (**an orifice or venturi, a valve**) is placed in a pipe, and the pressure is measured before and after the restriction.

   c. Since Bernoulli's theorem states that a drop in pressure is directly related to flow velocity, the difference in pressure or differential pressure can be used to (**infer flow, directly measure flow**).

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

9. Demonstrate the ability to:

   a. Field service a pressure regulator. (Job Sheet #1)

   b. Bench service a pressure regulator. (Job Sheet #2)

PRINCIPLES OF PNEUMATICS
UNIT I

ANSWERS TO TEST

1.
   - a. 4
   - b. 7
   - c. 2
   - d. 6
   - e. 9
   - f. 10
   - g. 8
   - h. 1
   - i. 5
   - j. 3

2. a, b, c

3.
   - a.
     - 1) Pressure
     - 2) Volume
     - 3) Temperature
   - b. The other two variables are known
   - c. The relationship of the other two can be determined
   - d. P1 initial, P2 resulting
     V1 initial, V2 resulting
     T1 initial, T2 resulting

4. Energy cannot be created or destroyed, but it can be transformed from one form to another

5.
   - a. Equally
   - b. Contents
   - c. The area

6.
   - a. The pressure will decrease
   - b. The pressure will increase

7.
   - a. Calibrate
   - b. Square centimeter
   - c. Fluid-filled vessel
   - d. Fluid
   - e. A known pressure

ANSWERS TO TEST

8. a. Liquid flow
   b. An orifice or venturi
   c. Infer flow

9. a. Evaluated according to criteria in Practical Test #1
   b. Evaluated according to criteria in Practical Test #2

CALIBRATION STANDARDS AND TEST EQUIPMENT

UNIT II

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss calibration standards for length, mass, time, electricity, temperature, and light. The student should also be able to define standards used in process instrumentation, and relate specifications for accuracy, sensitivity, repeatibility, and permanence to their objectives in process control devices and systems. The student should be able to calibrate instruments used in process control, and use test equipment for troubleshooting system problems. These competencies will be evidenced by correctly completing the procedures outlined in the job sheets, and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to calibrations and measurements with their correct definitions.
2. Complete statements concerning calibration standards.
3. Solve problems concerning standards for length.
4. Solve problems concerning standards for mass.
5. Complete statements concerning standards for time.
6. Solve problems concerning standards for electricity.
7. Solve problems concerning standards for temperature.
8. Solve problems concerning standards for light.
9. Select true statements concerning national standards.
10. Complete statements concerning primary standards.
11. Complete statements concerning secondary standards.
12. Complete statements concerning shop or working standards.
13. Complete statements concerning manufacturers' specifications.

OBJECTIVE SHEET

14. Select true statements concerning specifications for accuracy.
15. Solve problems concerning specifications for sensitivity.
16. Select true statements concerning specifications for repeatability.
17. Solve problems concerning specifications for permanence.
18. Select true statements concerning other parameters and applications.
19. Complete statements concerning deadweight testers.
20. Solve problems concerning manometers.
21. Select true statements concerning potentiometers.
22. Solve problems concerning frequency meters.
23. Select true statements concerning digital VOMs.
24. Select true statements concerning decade resistance boxes.
25. Complete statements concerning thermal and ice baths.
26. Solve problems concerning thermometers.
27. Select true statements concerning oscilloscopes.
28. Complete statements concerning pneumatic calibrators.
29. Select true statements concerning precision power and current supplies.
30. Solve problems concerning calibration tools and materials.
31. Demonstrate the ability to:
    a. Calibrate a test gauge with a pneumatic deadweight tester. (Job Sheet #1)
    b. Calibrate a test gauge with a hydraulic deadweight tester. (Job Sheet #2)

CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information and assignment sheet.

C. Discuss unit and specific objectives.

D. Discuss information sheet.

E. Read the handouts carefully, and have graph paper available so students can practice making calibration curves.

F. Demonstrate the procedures outlined in the job sheets, and emphasize the importance of both safety and cleanliness when working with a deadweight tester.

G. Give test

REFERENCES USED IN DEVELOPING THIS UNIT

A. Gillum, Donald R. *Control Loop Systems*. Austin, TX: Extension Instruction and Materials Center, Division of Continuing Education, The University of Texas at Austin, 1984.

B. Liptak, Bela G. *Instrumentation Processing in the Industries*. Philadelphia, PA: Chilton Book Company, 1973.

C. *Instrumentation Basics, Module C, Instrumentation Test Instruments*. Research Triangle Park, NC 27709: Instrument Society of America, 1981.

D. *Instrumentation Maintenance, Module 1, Errors in Measuring Instruments*. Research Triangle Park, NC 27709: Instrument Society of America, 1982.

CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

INFORMATION SHEET

I. **Terms and definitions**

   A. ISO (International Standards Organization) — A Paris based international standards agency that establishes metric standards

   B. IBWM (International Bureau of Weights and Measures) — The official headquarters of the ISO metric system of weights and measures; it is based in Paris, France

   C. SI (International System of Units) — The standard metric measures used world wide, and officially abbreviated SI

   D. NBS (National Bureau of Standards) — The official United States agency that establishes and maintains standards, including primary standards or replicas used in America

   E. IEC (International Electrotechnical Commission) — An international commission that sets and disseminates working electrical standards from its headquarters in Geneva, Switzerland

   F. ANSI (American National Standards Institute) — An industry/government sponsored agency in New York City that sets and disseminates standards information for the U.S.

   G. ISA (Instrument Society of America) — A U.S. technical society that establishes process instrumentation standards in conjunction with NBS and industry

   H. IEEE (Institute of Electrical and Electronic Engineers) — An American technical society that works with NBS and industry to establish electrical/electronic standards

   I. NFPA (National Fire Protection Association) — An agency formed by insurance companies to set standards for fire safety, including wiring and instrumentation

   J. sr (Steradian) — A unit used in solid geometry to describe the angle in radians projected from the center of a sphere

II. **Calibration standards**

   A. There are six international standards or physical measures from which all other measures are derived.

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B. The calibration measures are:

1. Length

2. Mass

3. Time

4. Electricity

5. Temperature

6. Light

III. **Standards for length**

A. The SI unit for length is the meter, abbreviated m.

B. The length of a m is 1,650,763.73 wavelengths of light from krypton 86 (the orange-red line in the spectrum).

C. Area in square meters (m sq.), and volume in cubic meters (m cu.) are both derived from the length standard.

IV. **Standards for mass**

A. The SI unit for mass is the kilogram, abbreviated kg.

B. Mass is the only basic physical unit of measure that is an actual physical device.

C. The original kg mass is a cylinder of a platinum/iridium alloy kept by the IBWM in Paris, while an exact duplicate is housed in the NBS facilities in the U.S.

(NOTE: The unit of mass is the only remaining standard that relies on a physical entity, and all the other standards can be reproduced anywhere the expertise is present and the equipment is available.)

D. Derived standards include Force in newtons, N, where one newton force applied for one second will give a mass of one kg a speed of one m per second.

E. The SI unit of force in newtons will yield the SI unit for work, the joule, J, where one joule is one newton force times one meter, or J=Nxm.

F. The SI unit of work will yield the SI unit of power, the watt, W, which is defined as one unit of work (or energy) joule per second, or W=J/s.

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V. **Standards for time**

   A. The SI unit for time is the second, abbreviated s.

   B. The time unit is produced with a cesium clock by measuring the duration of 9,192,631,770 cycles of radiation from cesium under controlled conditions.

   C. The time standard is reproducible anywhere in the world because it is the result of natural phenomena, not a physical device stored at a location.

   D. A derived SI standard includes frequency or cycles per second in hertz, Hz.

   E. The frequency unit describes the number of transitions that an alternating waveform makes during a second.

   F. In conjunction with the meter unit, the time unit is also used to derive speed in meters per second, and acceleration in meters per second.

VI. **Standards for electricity**

   A. There are three SI units for electricity:

      1. Ampere

      2. Volt

      3. Ohm

   B. The key unit for deriving the electricity standard is the ampere, A, which is used to measure electrical current flow.

   C. The ampere unit measures the force of the magnetic field between two parallel wires, one meter apart, that produce .0000007 newtons per meter of length per ampere.

   D. The Volt, V, is the electrical pressure applied to a circuit with a resistance of one Ohm, Ω, which will result in one ampere current flow.

   E. The relationship known as Ohms law finds a one to one relationship between volts, amperes, and ohms, where $V = A \times \Omega$.

   F. The Ohms law relationship can also show power in watts, W, where $W = A^2 \times \Omega$.

VII. **Standards for temperature**

   A. The SI unit for temperature is shown in degrees kelvin, abbreviated K.

   B. The SI K unit is based on the triple point of water, the point where it is solid, liquid, or gas, and is found to be 0.01 degree celsius.

INFORMATION SHEET

C. Celsius is a scale derived from Kelvin; however, it is easier to set the standard at Kelvin's absolute zero point for the sake of producing standards that can be reproduced anywhere

VIII. **Standards for light**

A. The SI unit for light or luminous intensity is the Candela, abbreviated cd.

B. The SI unit is found by measuring the monochromatic (single frequency) radiation (light) from a source in a single direction that will produce 1/683 of a watt per steradian at a frequency of 540,000,000,000,000 Hz.

IX. **National standards**

A. Each nation has organizations such as the NBS in the U.S. that implement systems to comply with international standards.

B. National standards assure that no matter where products are produced, as long as they are produced to standard measures, they will work with other products.

C. Within the past ten years, metric measure has become commonly used in the U.S. because of an increased dependence on world trade, and use of metrics will become more important in years to come.

D. The National Bureau of Standards has laboratories in Washington, D.C., and in Boulder, Colorado.

E. Overseeing standards is a task far too large for the NBS alone, and the government has delegated part of the job to a network of professional organizations to help in the generation of standards and the dissemination of information about standards.

F. Organizations such as IEEE, ISA, NFPA, and ANSI have access to technical expertise from business, industry, and education, that the government cannot afford to maintain, and the cooperative arrangement between government and professional organizations frees the NBS to administer and coordinate widespread activities.

G. The coordination makes it possible for all parts of society to have access to measures based on standards, and these standards are based on three different levels:

1. Primary standards;
2. Secondary standards;
3. Shop or working standards.

INFORMATION SHEET

X. **Primary standards**

A. A primary standard is the initial test set-up, or a device to which all other standards trace their origin.

B. Most primary standards are held by the NBS; however, occasionally, a major industry may be designated to be the primary source.

C. All standards of a particular measure can be traced to the primary, and all other standards must be recertified periodically to the primary.

XI. **Secondary standards**

A. Secondary standards are calibration devices entrusted to manufacturers, test and calibration laboratories, or calibrating agencies.

B. Secondary standards are directly traceable to primary standards, and are used only to calibrate working standards.

XII. **Shop or working standards**

A. The standards that manufacturers use to produce products, and the standards used by business for commerce and trade are called shop or working standards.

B. All shop or working standards are traceable to the primary standards by way of the secondary standards used by calibration service agencies.

C. Shop standards must be recalibrated often to maintain system integrity, and calibration records should be filed for reference.

EXAMPLE: The Nuclear Regulator Commission (NRC) requires regularly schedules calibrations for instruments used to monitor and control a nuclear reactor. Extremely critical instruments require calibration more often than other devices. The NRC also requires careful preparation and maintenance of calibration recores.

D. As a rule of thumb, a working standard such as a test gauge should have an accuracy ten times greater than the gauge or device it is used to test.

XIII. **Manufacturers' specifications** (Transparency 1)

A. Manufacturers of process control systems and devices have specifications for their products, and these specifications are essential for proper operation of equipment.

B. Specifications appear in documents such as instruction books or equipment manuals, and deal with matters of equipment design and equipment applications.

INFORMATION SHEET

XIV. **Specifications for accuracy** (Transparency 1)

A. Because accuracy is the heart of all measuring concerns in process instrumentation, it is an extremely important specification.

B. Accuracy expresses how close a measuring device comes to indicating the actual quantity being measured.

C. Accuracy is always measured with a shop standard and expressed as plus or minus (±) percent of full scale output.

XV. **Specifications for sensitivity**

A. Sensitivity refers to the smallest measurement a control system can detect and act on.

B. If a sensor can detect a change of ten micrometers in a process, and the system can act on a signal that small, then the system has a sensitivity of ten micrometers.

C. Sensitivity specifications are important because they express the capacity of a system to provide information that reflects conditions much too small for a person to detect.

XVI. **Specifications for repeatability** (Transparency 1)

A. Repeatability expresses the ability of an instrument to produce the same result time after time from a given input in the same direction.

B. Repeatibility is expressed as plus or minus (±) percent of span to express the maximum difference between output readings.

XVII. **Specifications for permanence**

A. Permanence could well be called durability because it provides a user with a specified time in hours, days, or months that the equipment can be used before it will need maintenance or repair.

B. Permanence is also the measure of the useful life of an instrument, for even when an instrument is not physically worn out, it may be worn to a point where accuracy and repeatability are not acceptable.

XVIII. **Other parameters and applications**

A. Other than the four key specifications, user's manuals may contain information about linearity, speed, range, and resolution.

B. Installation instructions will contain considerations for special environmental controls for fire and explosion protection and other control requirements.

INFORMATION SHEET

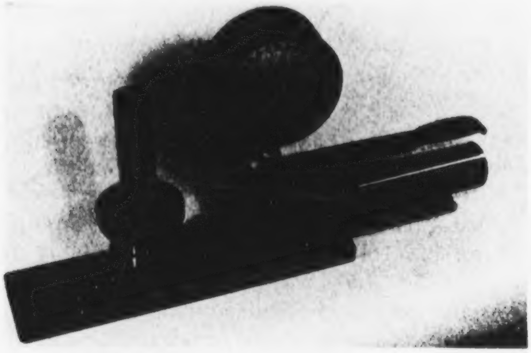
C. Installation instructions will also list limitations equipment may have with respect to location, application, or operating procedures.

D. A manual will also give routine calibration checks, and may include procedures for recalibration if standards are available.

XIX. **Deadweight testers** (Figure 1)

A. A deadweight tester consists of a weight table mounted on a piston so that weights placed on the table will cause the piston to apply weight (mass) to the oil reservoir as weight per square area of the piston.

FIGURE 1



B. According to Pascal's principle, the fluid pressure in a closed system is distributed equally in all directions, so when a hydraulic device such as a gauge is attached to the reservoir, the pressure applied to the piston in pounds or kilograms can be used to calibrate the device.

C. A deadweight tester is complicated in that a hydraulic hand pump is required to balance the system, and the piston attached to the weight must be lubricated in some way to remove the influence of friction.

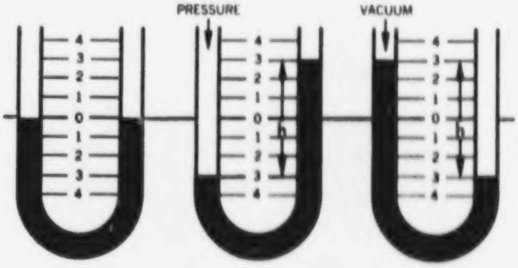
XX. **Manometers** (Figure 2)

A. A manometer is a device used to measure pressure.

INFORMATION SHEET

B. U-tube manometers are made of glass or plastic, and filled with a liquid of a known specific gravity.

FIGURE 2



Courtesy Dwyer Instruments Inc.

C. When pressure is applied to one leg of a manometer, liquid in that leg is pushed down, and the liquid in the opposite leg moves up proportionally.

D. The difference in the height of the two legs, and the specific gravity of density of the liquid will yield the pressure applied to the gauge.

E. The formula for working with a manometer is: $P = dh$ where:

1. P is pressure in pounds per square inch or kilograms per square centimeter.
2. d is density or specific gravity in pounds per cubic inch or kilograms per cubic centimeter
3. h is the difference in height of the two legs in inches or centimeters.

EXAMPLE: In a U-tube filled with Mercury which has a density of 0.49 pounds per cubic inch, the two legs would first be equalized by opening both sides to the atmosphere, and then pressure would be applied to one leg, and the difference in the height of the legs measured; the pressure would be the difference in leg measurements multiplied by the density of the liquid. In this example, if the difference were 4 inches, the pressure would be equal to 4 inches × 0.49/inches cubed, or 1.96 pounds per cubic inch.

F. Water is another common liquid used in manometers, and it has a specific gravity or density of 0.0361 pounds per cubic inch.

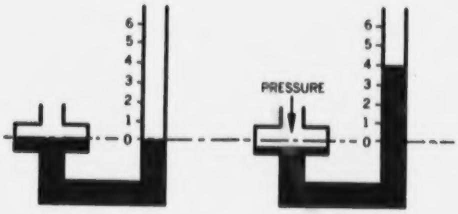
INFORMATION SHEET

G. Because of the limited range, a manometer is used only in low pressure applications, and another manometer limitation is that temperature will cause expansion and contraction of the liquid.

H. Some manometers have one leg replaced by a metal well with a large surface area, and changes in height of the remaining leg are measured to yield the h dimension for the formulation of pressure.

I. Well type manometers are much more rugged than U-tube manometers. (Figure 3)

FIGURE 3

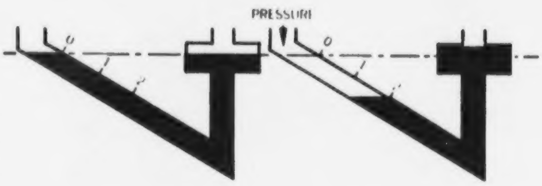


Courtesy Dwyer Instruments Inc.

J. Another manometer variation is the inclined tube manometer where the tube is inclined at a shallow angle to the horizontal surface of the well instead of being vertical.

K. An inclined manometer can measure very small pressure changes because slight changes in vertical movement of the liquid produce large horizontal movements along the tube. (Figure 4)

FIGURE 4



Courtesy Dwyer Instruments Inc.

INFORMATION SHEET

XXI. **Potentiometers** (Figure 5)

A. A potentiometer measures electrical pressure difference by measuring or metering voltage in a system.

B. A potentiometer is a variable resistor device used to divide a known voltage into a smaller increment that can be compared to another unknown small voltage from a sensor or transducer output.

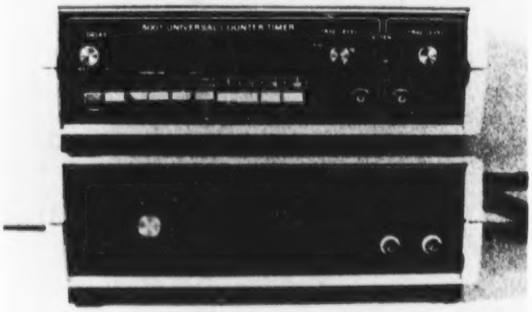
FIGURE 5

C. Potentiometers are normally used to measure direct current; however, if special inductive coils are used, a potentiometer can also measure alternating current.

XXII. **Frequency meters** (Figure 6)

A. A frequency meter can measure, and display or record the frequency of an AC source such as the output from an AC operated ultrasonic generator.

FIGURE 6



INFORMATION SHEET

B. In the case of an ultrasonic generator that drives a measurement and control system, the frequency is critical to the system, but the output is neither audible or visible to an operator.

C. When a frequency meter is connected across the output terminals of an ultrasonic generator, and set for the appropriate range of frequencies (approximately 500 kHz), the meter will produce a readout of generator output in numeric form.

D. Most frequency meters will measure time periods as well as frequency, and many frequency meters can be used as counters.

E. Almost all frequency meters will respond to almost any AC form such as sine, square, sawtooth, and triangular waveforms.

XXIII. **Digital VOMs** (Figure 7)

A. A digital VOM measures and displays DC and AC electrical voltage (pressure), ohms (resistance), and milliamperes (current flow) in numeric form.

FIGURE 7

B. Analog meters with swinging pointers were once favorite troubleshooting tools, but digital VOMs are more accurate, smaller, lower in cost, and much more rugged.

C. With the advent of high speed digital signals, the digital VOM has another distinct advantage because it can read a variable correctly, but an analog meter is limited to lower frequencies.

INFORMATION SHEET

XXIV. **Decade resistance boxes** (Figure 8)

A. A decade resistance box is a box of calibrated precision resistors which allows a user to switch a decade level of resistance with each switch.

B. In a decade resistance box, the decades are usually 1s, 10s, 100s, 1000s, 10000s, 100,000s, and finally, megaohms, and the box would have seven switches so that the user can select from 1 ohm to 10,999,999 ohms in one ohm steps.

FIGURE 8

C. The box is designed to provide technicians with the capability of duplicating any resistor value necessary to calibrate an electrical system or component.

D. Decade resistance boxes must be used with skill because the percentage of accuracy is less than the highest precision of the lowest precision part because the series arrangement creates a cumulative error problem in the total resistance of the box.

E. One way around the cumulative error problem is to use fewer decades which requires more boxes with different segments of the total resistance range.

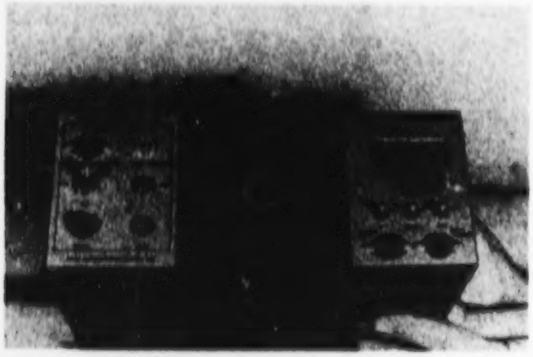
INFORMATION SHEET

XXV. Thermal and ice baths (Figure 9)

A. The thermal bath is a device used in calibrating thermal sensors, transducers, and control devices.

B. The thermal bath is an insulated vessel that has a precision controlled temperature capability so that when it is filled with liquid the bath can provide the range of temperatures needed for calibrating thermal equipment.

FIGURE 9



C. Some thermal baths are designed almost as simple as a thermos bottle, but they range up to expensive units with programmable precision temperature ranges that are computer controlled.

D. Ice baths are designed to maintain liquid used in a test at the temperature of melting ice.

XXVI. Thermometers (Figure 10)

A. A calibration-grade thermometer is made of stress-relieved pyrex glass with a bore (hole) precisely manufactured and tested.

B. Special precision scales are made for lab thermometers, and all components go through exhaustive testing before the thermometer is precision filled, and tested again.

INFORMATION SHEET

C. The final unit is mounted in a precision case which provides protection for the glass, and makes reading the scale easier.

FIGURE 10

XXVII. **Oscilloscopes** (Figure 11)

A. The high frequency, precision, portable oscilloscope is rapidly becoming the instrument preferred by technicians because it is easy to use, and gives much more information than other instruments.

FIGURE 11

B. An oscilloscope receives electrical signals, and displays them on a video screen as a plot of voltage in the vertical direction, and time in the horizontal direction.

C. Measuring electrical quantities with a standard meter leaves a chance for error, but an oscilloscope permits a technician to watch the dynamic action of a system, and actually see the problem.

INFORMATION SHEET

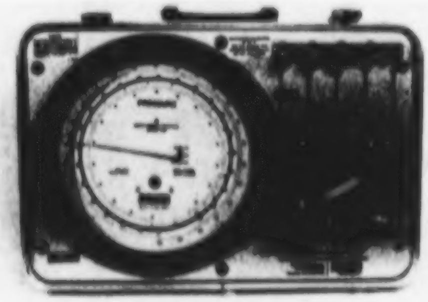
D. Some oscilloscopes have memory so that two or more pieces of information can be stored and retrieved later for evaluation.

E. Some oscilloscopes can produce a hardcopy printout, and other oscilloscopes can be interfaced with a computer/printer to provide printouts.

XXVIII. **Pneumatic calibrators** (Figure 12)

A. A pneumatic calibrator is a portable test instrument used to troubleshoot and calibrate pneumatic devices.

FIGURE 12



B. Pneuamatic calibrators are used for bench testing, but can also be used for field calibration so that a technician will not have to remove equipment and take it back to the shop.

C. Some pneumatic calibrators are available with their own internal air supplies, 24 or 48v DC power supplies, and digital readouts.

XXIX. **Precision power and current supplies** (Figure 13)

A. Precision power supplies provide voltages and currents used in calibration.

B. Voltage sources usually have some range of output voltage adjustable to test requirements, and a very small tolerance for error in voltage, sometimes as low as 0.005%.

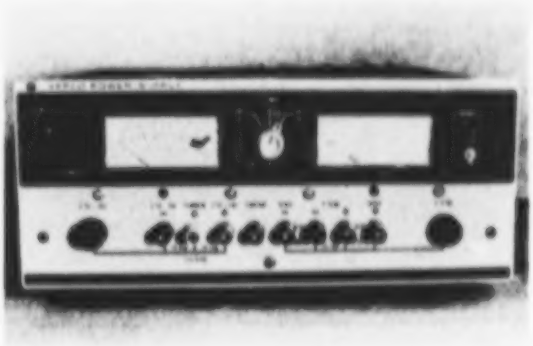
C. Voltage sources also have a system for detecting and protecting the power supply from severe load changes, and current limits can usually be set on these instruments.

D. Current sources provide precision, constant current outputs set to the test requirements, and held within a close tolerance of 1% or better.

INFORMATION SHEET

E. Current sources also have a very fast recovery time (several hundred microseconds to a few milliseconds) from changes in the load.

FIGURE 13



XXX. **Calibration tools and materials**

A. Most technicians carry a DVOM for field troubleshooting and calibration.

B. Basic hand tools and supplies are usually carried in a belted tool pouch, and usually include:

1. An assortment of flat-blade and Phillips screwdrivers and a jeweler's screwdriver;
2. An assortment of pliers including channel-lock, needle-nose, side-cutting, and diagonal-cutting;
3. A set of combination wrenches up to ¾";
4. An electrician's 6-in-1 tool for cutting wires, stripping insulation, and crimping connections;
5. Electrical tape, teflon tape, and regular pipe dope;
6. A set of adjustable wrenches;
7. A set of hex keys (allen wrenches).

C. What tools a technician carries depends on the demands of the installation, and technicians quickly learn what tools are needed for given circumstances.

EXAMPLE: Pipe wrenches are usually keep in the shop, but some technicians carry them in the field. One pair of channel-lock pliers is usually enough, but some technicians carry two so they can use one pair for backup.

INFORMATION SHEET

D. Shop tools used for bench repair and calibration activities vary with the type of installation, but should include:

1. A set of pipe wrenches;
2. Wire brushes;
3. A socket set and ratchet;
4. A tubing cutting and tubing bender;
5. A hacksaw;
6. A soldering gun, solder, and soldering flux;
7. A butane torch;
8. A pry bar.

E. Both shop and portable tools should be used for their intended purposes, and should be kept clean and in good working order.

F. Many cleaning materials are flammable, and should be safely used and properly stored.

G. All technicians should wear safety glasses when working on equipment or any time they are exposed to a potential eye hazard.

H. Rules vary from installation to installation, but some environments require technicians to wear hard hats, and some installations require protective clothing.

Bailey Pneumatic Computer/Controller Specifications

Accuracy†	Factory calibrated (as differential-proportional controller)* to be accurate within ±0.5% of span at Gain = 1.
Input/Output Signal Range	3-15 psig (20.7 to 103 kPa).
External Connections	1/8 inch - 27 NPT female.
Operating Conditions	Normal Ambient Temperature: 40° to 140°F (4.4° to 60°C). Extreme: −20° to 160°F (−29° to 71°C).
Repeatability	0.2% at Gain = 1.
Deadband	0.05% of output span.
Temperature Effect	±2% for 100°F (55°C) with Gains 0.2 to 5.0.
Air Supply	18-20 psig (124 to 138 kPa) for 3-15 psig (20.7 to 103 kPa) signal range recommended, 25 psig (172 kPa) maximum.
Steady State Air Consumption	0.07 scfm ($.330 \times 10^{-4} m^3/S$).
Supply Pressure Effect	0.25%/psi.
Supply Capacity (one psi drop in output)	1.0 scfm ($4.72 \times 10^{-4} m^3/S$).

Exhaust Capacity (one psi increase in output)	1.0 scfm ($7.55 \times 10^{-4} m^3/S$).
Position Sensitivity (30° any direction)	±1% of input span.
Vibration Effect	Tested in accordance with MIL STD 167B.
Independent Linearity	±0.25%.
Weight	Net: 8.3 lbs. (3.77 kg) Shipping: 11 lbs. (4.99 kg)
Gain Range	.2 to 20.
Integral Range	.05 to 100 repeats per minute
Derivative Range	.1 to 10 minutes

†As defined by SAMA Standard PMC20.1.

*Minor field adjustment may be required when used for other functions.

NOTE:
All data at mid-range reference conditions:
Temperature: 75°F (24°C) ±5°F (±3°C).
Supply Pressure: 18-20 psi (124 to 138 kPa).
Gain = 1. (where applicable)

Courtesy Bailey Controls Company

CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

HANDOUT #1 — THE FIVE-POINT CHECK

Background

A five-point check is used to determine if instruments are properly calibrated, and is a tried-and-true routine for determining linearity. The five-point check is so named because the procedure uses a calibration standard such as a deadweight tester or comparator to check output at five different points within the range of the instrument under test. The five-point checks are usually performed at 10, 30, 50, 70, and 90 percent of output. Because most instruments operate in the range of 10 to 90 percent in normal operation, the zero and 100 percent readings are not as important and are therefore not included in the check.

Calibration data

The five-point check is easy to follow in chart form. Chart 1 shows calibration data for a pneumatic device which works with the 3-15 pounds per square inch (psi) pneumatic standard. For convenience, Chart 1 is on a separate page that accompanies this handout. Examine the chart a moment. The far left column shows the five-step range in percentages. The far right column shows output in psi based on the 3-15 psi standard. Note in Chart 1 that 10% is equal to 4.2 psi. This is true because the 3-15 standard has a span of 12 (15 − 3 = 12). Since 10% of 12 is 1.2, the 1.2 has to be added to 3.0 to arrive at an output of 4.2 psi.

The five-point formula for psi

There are a couple of formulas that make the five-point check easy to work with. The PSI Formula is: % × 12 + 3.00 = output in psi. Let's use the decimal equivalent of 70% to verify the formula. Check the 70% input in Chart 1 as we verify. .70 × 12 = 8.4 + 3.0 = 11.4 psi. The formula works. Note also that the 10 to 90 percent inputs have output values that do not change.

The five-point formula for mA

Using the five-point formula for the mA conversion is also easy. In this case, 20 − 4 = 16 which means the span of the standard is 16. Since 10% of 16 is 1.6, the 1.6 has to be added to 4.0 to arrive at an output of 5.6 mA. The mA formula is % × 16 + 4.0 = output in mA. Checking the 70% mA input against the output in Chart 1 verifies that the formula work.

Relating various ranges to output

Now, let's look at Chart 2 where the input range is from 0 to 250 psi. Assume you are calibrating a pressure transmitter for a range of 0 to 250 psi. Note how the percent of input in the far left column relates to the actual input in psi. The calibration standard would have to be capable of the 0-250 psi transmitter range. Since 10% of 250 is 25, the standard should be set for 25 psi input to the pressure transmitter. If the transmitter is pneumatic, its output would be 4.2 psi. This is not difficult to determine because the psi outputs in the 3-15 psi standard remain constant with the percentage of input.

HANDOUT #1

Graphing a five-point check

Once information is gathered for a five-point check, the information can be used to prepare a graph that will show the relationship of percent of input to percent of output. This will help a technician determine if the instrument is properly calibrated. If the instrument is properly calibrated, the graph will display the linear output, and the technician can quickly determine that no further calibration is required. If the graph displays other than linear output, the technician can quickly identify the problem. We will talk more about measurement errors in Handout #3, but for now let's look at Graph 1 that accompanies this handout to see how the output of a properly calibrated device displays linearity. Let's use the information from Chart 2. By graphing the % of output on the vertical scale and the % of input on the horizontal scale, we see that the output remains linear throughout the 0-250 psi span. Graph 1 includes the output readings and the input pressures from the standard so you can better visualize what is going on.

Conclusion

Graphing information gathered in a five-point check provides a quick, reliable reference for troubleshooting. If any of the outputs in the graph differ from the ideal values shown, a technician can spot non-linearity, and errors in zero and span.

The five point check is a generally accepted method for calibrating instruments with pneumatic or electrical outputs. Since the output remains constant with the percent of input, the technician has to calculate only the percentage of input and compare the input to the unchanging value of the output range. The five-point check is a valuable tool for technicians who must routinely calibrate instruments.

HANDOUT #1

CHART 1

% Input	Actual Value	Output mA	Output PSI	Pre-calibration
90		18.4	13.8	
70		15.2	11.4	
50		12.0	9.0	
30		8.4	6.6	
10		5.6	4.2	

CHART 2

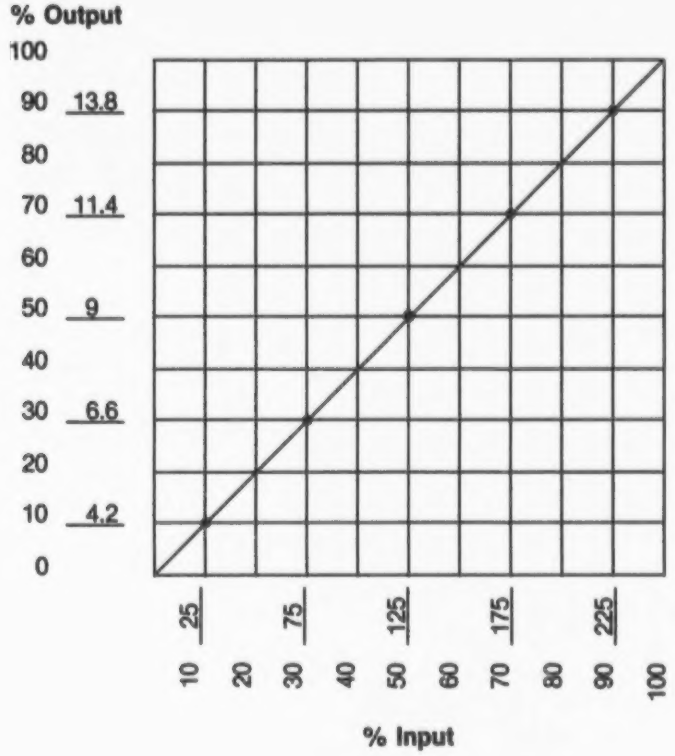
% Input	Calibration Standard Setting	Output mA	Output PSI
90	225	18.4	13.8
70	175	15.2	11.4
50	125	12.0	9.0
30	75	8.4	6.6
10	25	5.6	4.2

10% × 250 psi = 25 psi

HANDOUT # 1

GRAPH 1

% Input	Calibration Standard Setting	Transmitter Output in PSI
90	225	13.8
70	175	11.4
50	125	9
30	75	6.6
10	25	4.2



CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

HANDOUT #2 — DEVELOPING A CALIBRATION CURVE

Purpose

All instruments are subject to some degree of error. To find the degree of error, a technician must conduct a test of instrument performance. Test data should be recorded on a formal data sheet, and then the data should be used to plot a calibration curve on a calibration chart. The calibration curve will show how far an instrument deviates from the standard set for it. The amount of deviation will determine whether a device should be left in service or repaired or replaced. Proper calibration can be accomplished only by comparing instrument performance with a standard. If a technician wanted to calibrate a 0-15 psi test gauge, a pneumatic deadweight tester would be used as a secondary standard. The first step is to prepare a calibration data sheet.

Starting the Data Sheet

To serve its intended purpose, a data sheet should include the name and title of the technician making the test, the date the test is made, the name, serial number, and manufacturer of the instrument under test, and the name, serial number, and manufacturer of the standard used for the test. In the case of our example, the secondary standard is a deadweight tester, and the shop standard is the 0-15 psi test gauge. Some data sheets may also include whether calibration was done in the field or at a bench, and how long it took to complete the calibration. As you read through the information that follows, refer to the Calibration Data Sheet and Calibration Curve that accompany this handout.

Nominal and True Pressure

A column for nominal pressure would be prepared so that it shows the full range over which the gauge will be tested. Since we are testing a 0-15 psi test gauge, the range would be in increments of 1 psi from 0 to 15. Beside the column for nominal pressure should be a column for true pressure. True pressure is the adjustment for local gravity which differs with latitude and altitude. There is another slight adjustment that can be made for the buoyancy of the air surrounding the weights on the tester. Adjustment factors for local gravity should be available from your state bureau of weight and measures. Local architects or local surveyors may also have the information. Directions for adjusting for buoyancy should be in the manufacturers literature. For the sake of illustration, we will assume our 0-15 psi test gauge is being tested at sea level, and that nominal pressures and true pressures are equal.

Test Pressures and Deviations

The third column on the data sheet should be used for recording the readings from the gauge being tested. The fourth column on the data sheet should be used to record the + or − deviation. In our example, when a true pressure of 1 psi was applied from the deadweight tester, the gauge reading was 1.025 which means that the deviation was +.025. Deviation is the difference between true pressure and the reading on the gauge being tested.

HANDOUT #2

Preparing the Calibration Chart

The next step in preparing a calibration curve is to plot all deviations for the full range of the instrument under test. Note that unlike other charts, a calibration chart is divided at a vertical midpoint which represents a zero deviation line. This arrangement is so that + or – deviation can be clearly noted. Now, go to the deviations listed on the data sheet and plot them on the calibration chart. But hold everything! The calibration chart in the example shows minus deviation as plus, and plus deviation as minus. The chart is actually showing a "correction" factor. In other words, a minus deviation of .05 requires a plus .05 adjustment to correct the deviation. A plus deviation of .05 requires a minus .05 adjustment to correct the deviation. Simply put, the correction factor is always opposite the deviation.

Completing the Calibration Curve

Once dots have been placed at appropriate points on the calibration chart, the dots should be connected with a line. The line should be prominent enough to give the chart a profile. Connecting the dots with a line forms the calibration curve.

Conclusion

Preparing a calibration curve requires proper documentation as a device is being tested. Data gathered during testing will become a part of an instrument's history, and help other technicians solve future problems. With a little practice, a technician can learn how to plot a proper calibration curve, and how to use the curve to detect problems. In fact, a calibration curve is the handiest tool of all for detecting measurement errors, and those errors are discussed in depth in Handout #3.

HANDOUT #2

Calibration Data Sheet

Technician's Name: Dave Johnson Title: Tech II

Standard Used: Deadweight Tester

Manufacturer: Amatek Serial #: D-8611

Instrument Calibrated: 0-15 Pressure Gauge

Manufacturer: Dwyer Serial #: G-664

Date: 15 Mar 89 Field ☐ Bench ☑

Nominal Pressure	True Pressure	Measured Pressure	Deviation
0	0		
1	1	1.025	+.025
2	2	2.05	+.05
3	3	2.95	−.05
4	4	4.0	0
5	5	5.025	+.025
6	6	6.025	+.025
7	7	7	0
8	8	7.975	−.025
9	9	9.1	+.1
10	10	10.05	+.05
11	11	11.025	+.025
12	12	12	0
13	13	13	0
14	14	14.1	+.1
15	15	14.95	−.05

Start Time

9:30 AM

Completion Time

10:05 AM

Comments

zero correction for true pressure

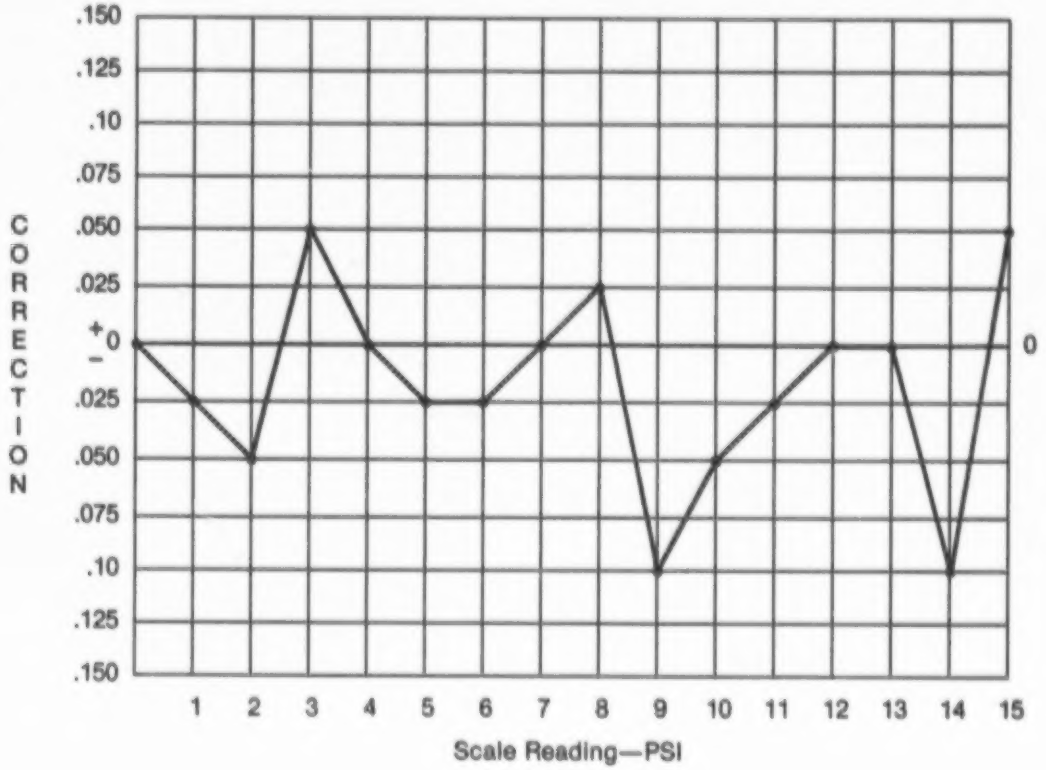
Prepare and attach a calibration curve to complete this data.

HANDOUT #2

Calibration Curve

Prepared by: D. Johnson Date: 15 Mar 89

Instrument Calibrated: Dwyer 0-15 Pressure Gauge Serial #: G-664



CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

HANDOUT #3 — MEASUREMENT ERRORS AND ACCURACY

Purpose

In calibration procedures there are errors that appear fairly often. Sometimes the errors are caused by equipment, and others are human errors. There are various physical techniques that can be used to avoid errors, and interpretation procedures to identify measurement errors.

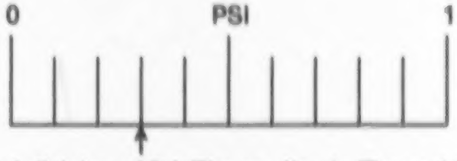
Observational Errors

Many observational errors result from simply misreading a gauge or a chart. The errors are frequently the result of viewing a scale from the wrong angle. With an analog test gauge, the misreading is often the result of parallax error. Parallax error can happen with almost any instrument that works with a scale and an indicator. This includes gauges, manometers, rotameters, electrical test instruments, and several other devices. To help avoid parallax error, some scale/indicator instruments have a mirror on the scale so that it will reflect the indicator. A technician viewing the gauge should close one eye, and then align the open eye over the indicator so that the indicator is aligned with the reflection in the mirror. Technicians working with scale/indicator instruments should read with care to avoid parallax error.

Misreading scales

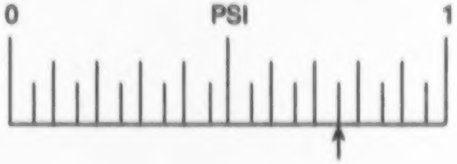
Another observational error results from misreading the subdivisions on a scale. To avoid this error, a technician should know exactly what the subdivision on a scale represents. Look at the scale in Figure 1.

FIGURE 1



The scale in Figure 1 has subdivision of 0.1. The reading in Figure 1 is 0.3 psi. Now, look at Figure 2.

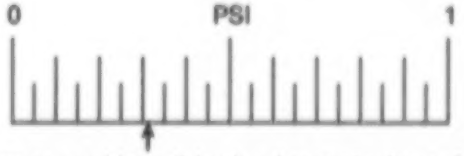
FIGURE 2



HANDOUT #3

The scale in Figure 2 has subdivisions of .05. The indicator in Figure 2 shows a reading of .75. Because the scale in Figure 2 has smaller scale increments and more subdivisions, it provides a greater degree of accuracy than the scale in Figure 1. Now, let's look at Figure 3.

FIGURE 3



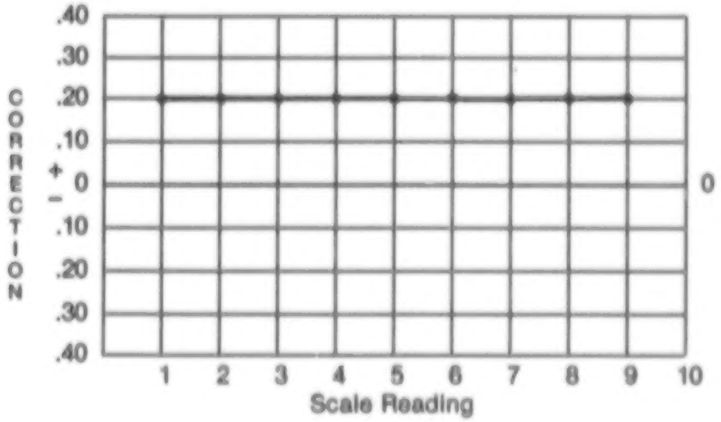
The reading in Figure 3 poses a problem. It is clearly greater than .3 psi, and clearly less than 3.5 psi. To read the scale in Figure 3 properly, a technician would have to make the following determinations.

1. If the indicator is closest to the halfway point between .3 and .350, and the subdivisions are .05, then the reading is .3 +.025 (half of .05) or .325 psi.
2. If the indicator is closer to .3 than .325, the reading should be called .3. This avoids carrying the reading to .315 or .320, or some other figure beyond the realistic accuracy of the gauge. By calling the reading .3, another technician may later read the instrument, use the rule outlined, and also call it .3. this insures precision and repeatability. Some facilities have different procedures for finite scale reading, but in general, the rule of selecting the nearest subdivision is a good one to follow.

Zero Error

Zero error results from failure to mechanically zero an instrument before it is calibrated. Zeroing means that the instrument should be set to the lowest end of its range. For instance, when calibrating a pressure gauge, if the indicator is .10 above zero when calibration begins, all measurements will be .10 too high and result in a zero error. When plotted on a calibration chart, the zero error is easy to detect because the profile of the calibration curve is either close to a straight line or is a straight line as shown in Figure 4. When a zero error is detected, the gauge should be properly zeroed and then rechecked for calibration.

FIGURE 4

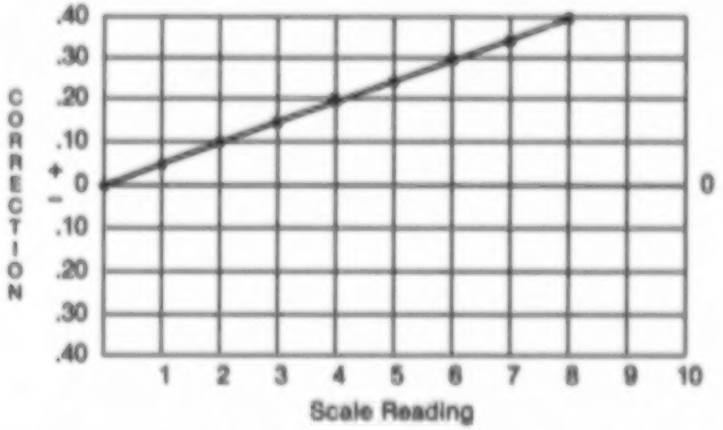


HANDOUT #3

Span Error

Span error may be caused by a defective component in an instrument, previous improper calibration, or vibration that produces value changes. When charted on a graph, the span error is easy to detect because it produces a sloping linear profile. This means that as input levels change, output levels change in equal amounts. The change in input from 1 to 2 psi produces an output change of .05 psi on the low end, and an input change from 9 to 10 psi also produces a .05 change in output on the high end. Figure 5 shows the profile that the span error would have on a calibration curve. Note that in summing output increments, all entries are .05.

FIGURE 5



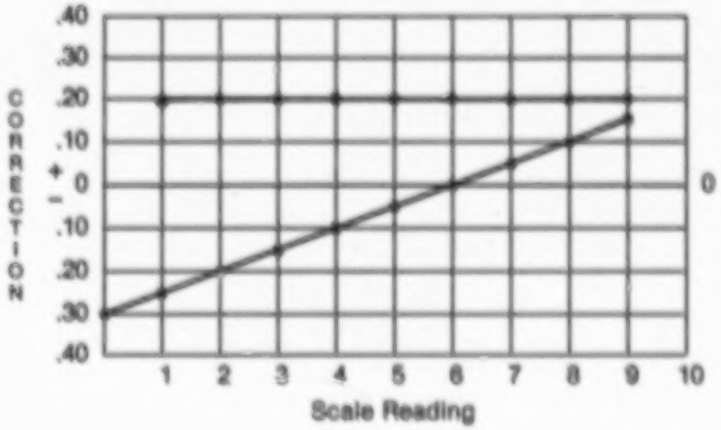
Recalibration is not always required after a zero error, but recalibration is always required after a span error. If the instrument cannot be recalibrated to a standard, it indicates a defective component that should be replaced.

Combination Zero/Span Error

The combination zero/span error happens when an instrument was not properly zeroed plus the instrument has a problem that produces value changes. Figure 6 shows what the combination error looks like on a chart. Technicians need to be aware of the combination zero/span error because it is routinely encountered in troubleshooting. What's more, initial calibration of an instrument will almost always require the technician to calibrate both span and zero.

HANDOUT #3

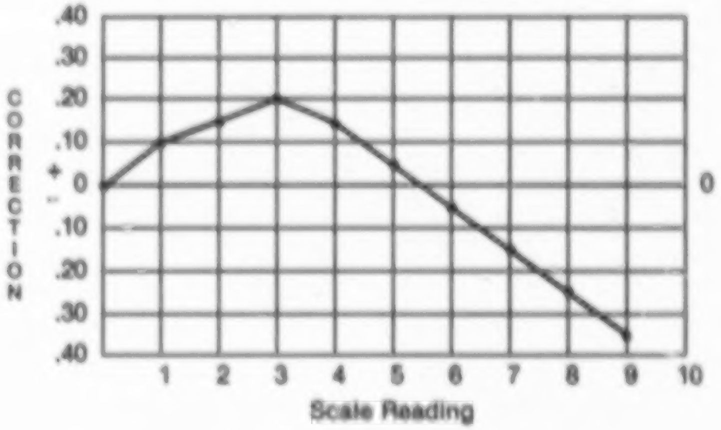
FIGURE 6



Non-Linear Error

A non-linear error is almost always an indication that an instrument can no longer be calibrated. The profile of a non-linear error is shown in Figure 7. Note how the profile moves up and down in a non-linear fashion. such a profile almost always means the instrument has to be replaced or repaired. When a non-linear error is detected, a technician should use the accuracy formula to determine if the instrument is beyond its acceptable percentage of accuracy.

FIGURE 7



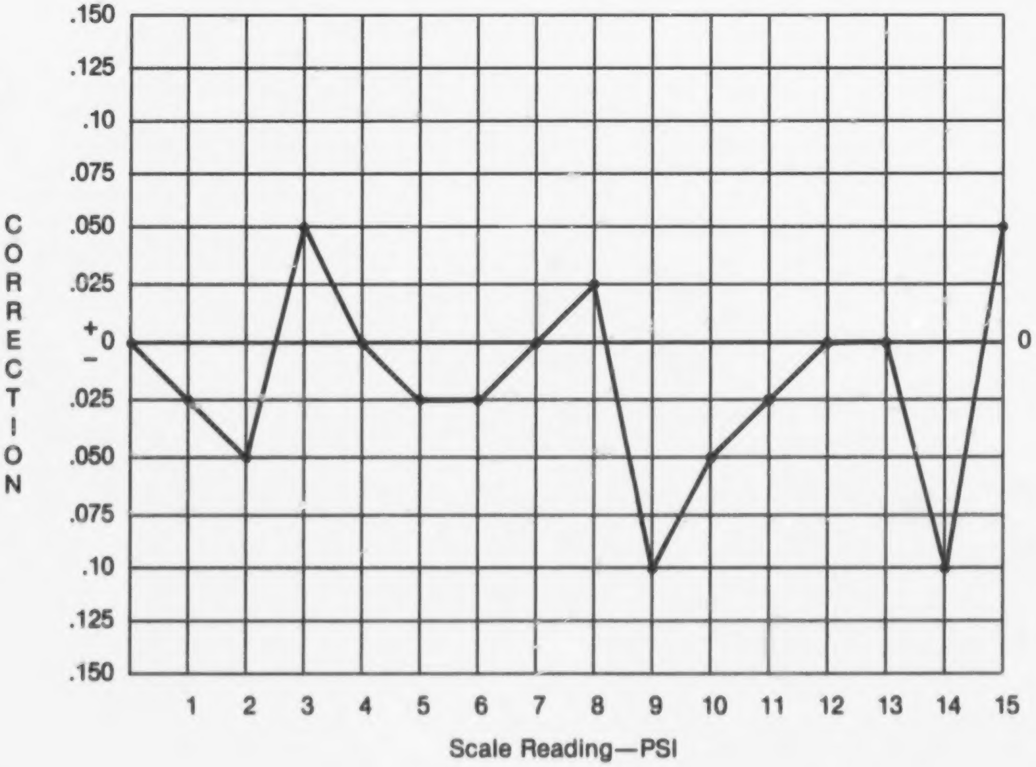
HANDOUT #3

Evaluating Accuracy

The accuracy of an instrument is its ability to perform to design standards as expressed in percentage. Depending on the instrument, the percentage may be a percentage of span, upper range value, scale length, or actual output. Naturally, different instruments require different formulas for determining accuracy. For the sake of demonstration, let's say that we are evaluating the accuracy of a pressure gauge. We know that gauge accuracy is expressed as a percentage of upper range limit. We also know that a test gauge would have an accuracy of ±.5 full scale. Let's assume we are working with a test gauge with a full scale of 0 to 15 psi. The calibration curve for the gauge was prepared, and is shown in Figure 8. So let's use Figure 8 to determine the accuracy of the tested gauge, and demonstrate how the accuracy formula works. To quickly determine if the gauge is accurate enough to comply with allowable deviation, select the point of greatest deviation from the calibration curve in Figure 8. If this point indicates the gauge is inaccurate, no other calculations will be needed to evaluate the instrument.

FIGURE 8

Calibration Curve



HANDOUT #3

The Accuracy Formula

The accuracy formula we are working with states that measured pressure subtracted from true pressure divided by the full scale reading times 100% is the percentage of accuracy of the instrument. In notation, the formula looks like this:

$$\frac{\text{True Pressure} - \text{Measured Pressure}}{\text{Full Scale Reading}} \times 100 = \%\ \text{of Full Scale Accuracy}$$

Of course, true pressure minus measured pressure is the deviation, so in essence the formula could also state that the deviation divided by full scale reading times 100% gives the percent of accuracy. Let's look at Figure 8 and put the accuracy formula to work.

The greatest deviation on the calibration chart is .10 at test pressures of 9 and 14 psi. Remember, the calibration curve shows a correction, so the actual measured pressure at 9 psi was 9.10, and that gives a deviation of .10. With the .10 deviation figure, and the full scale of 15 psi, we can begin our equation:

$$\frac{.10}{15} = .0066$$

Now, we multiply .0066 by 100% to get the percent of accuracy.

$$\frac{.10}{15} = .0006 \times 100 = .66\%\ \text{of Full Scale Accuracy}$$

What the formula really produces is the percentage of inaccuracy, but in instrumentation, the product is referred to as the percent of accuracy. Note that the .66% is beyond the allowable ±.5 standard of the gauge. The calibration curve has provided information that dictates that the gauge be repaired or replaced.

Conclusion

Preparing a calibration curve requires the collection of reliable data that can be compared with a standard. Accurate calibration data accomplishes much more than evaluating instrument accuracy. Knowing how much time is required for calibration would assist a supervisor in avoiding downtime. If recalibration would take too long, a new instrument would be put in service. Calibration data and the calibration curve become a part of instrument history. This history, in turn provides valuable information in evaluating system design, and repeated problems help manufacturers redesign instruments to provide better service.

CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

JOB SHEET #1 — CALIBRATE A TEST GAUGE WITH A PNEUMATIC DEADWEIGHT TESTER

A. Materials and equipment

1. Safety glasses
2. Pneumatic deadweight tester (Ametek RK 200 or equivalent)
3. Instruction material for selected deadweight tester
4. Air pressure regulator
5. 0-160 psi gauge
6. 0-15 psi Test Gauge (U.S. Gauge Model 1404 or equivalent)
7. Plastic hoses and fittings
8. Basic hand tools
9. Clean gloves
10. Pencil

B. Routine #1 — Setting up the pneumatic deadweight tester

1. Put on safety glasses, and keep them on!
2. Arrange equipment near the bench air supply.
3. Connect equipment as indicated in Figure 1 that accompanies this job sheet.
4. Check the zero of the Test Gauge.
5. Make zero adjustments as required on test instruments.

   (NOTE: Check with your instructor for help with zeroing procedurings, or for required tools.)
6. Set the INLET VALVE on the deadweight tester to OFF.
7. Set the OUTLET VALVE on the deadweight tester to VENT.

   (CAUTION: Before turning on bench air, make sure the air pressure regulator control is turned counterclockwise so that it is OFF.)

JOB SHEET #1

8. Open bench air valve SLOWLY.

9. Adjust air pressure regulator for a 40 psi reading on Pressure Indicator 1.

10. Close bench air supply immediately if there are any leaks, and stop the leaks.

11. Put on a pair of clean gloves, and remember to never touch deadweight tester weights without gloves on.

12. Install the corrector weight which, along with the ball and weight carrier, will give a 1 psi reading in Step 14.

13. Turn the deadweight tester INLET VALVE to HI RANGE and the OUTLET VALVE to ON.

14. Check for a reading of 1 psi on the Test Gauge on the deadweight tester OUTLET.

15. Check with your instructor if you fail to get the proper 1 psi reading in Step 14.

16. Turn the OUTLET to OFF.
    a. If there are no leaks, the 1 psi on the indicator and gauges will hold.
    b. If pressure drops, this indicates leaks, so turn off bench air supply.
    c. Check hoses and connections as required.

17. Continue until you get the proper 1 psi reading on the Test Gauge.

    ☐ Have your instructor check your work.

C. Routine #2 — Calibrating the Test Gauge

1. Wear your safety glasses and gloves.

2. Add weights as required to obtain the nominal pressures indicated on the Data Sheet that accompanies this job sheet.

3. Record all pressure readings for the Test Gauge under the column for Measured Pressure.

4. Close the bench air supply when all readings are completed.

5. Turn the deadweight tester INLET VALVE to OFF, and turn the OUTLET VALVE to VENT.

6. Disassemble test apparatus, and return all equipment to proper storage.

   ☐ Have your instructor check your work.

JOB SHEET #1

D. Routine #3 — Preparing calibration curves

1. Fill in the column for True Pressure on your data sheet only if you have the conversion factor for local gravity.

2. Use the formula Nominal Pressure × Conversion Factor = True Pressure to complete your True Pressure entries.

   (NOTE: If you do not have a conversion factor for local gravity, assume that the calibration is being performed at sea level and that nominal and true pressures are equal.)

3. Calculate the deviation for the Test Gauge through its full range of 1 - 15 psi.

4. Plot a calibration curve for the Test Gauge.

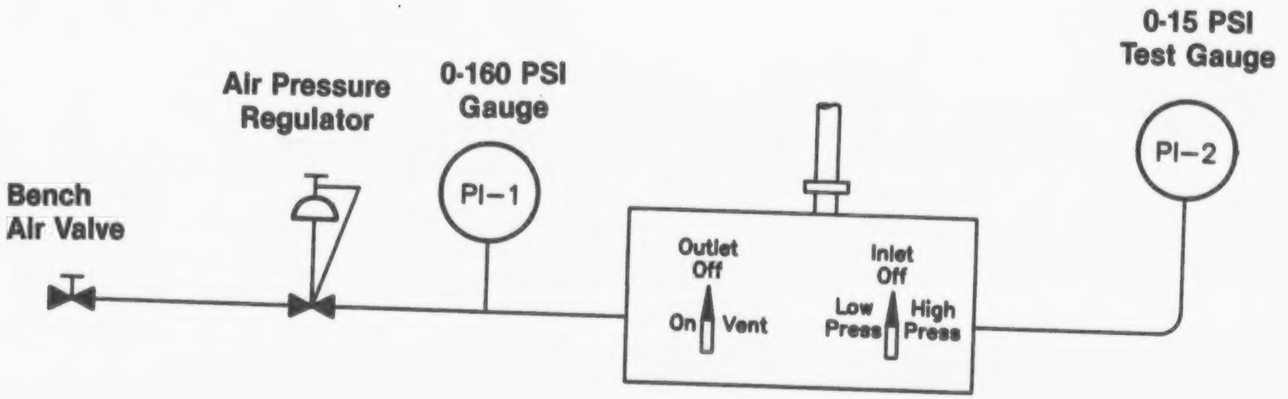
   (NOTE: Remember that the readings on the calibration curve are equal, but opposite in polarity to the deviation readings.)

   ☐ Have your instructor check your calibration curves.

5. Clean area, and make sure all equipment and materials are returned to proper storage.

JOB SHEET #1

FIGURE 1


Bench
Air Valve
Air Pressure
Regulator
0-160 PSI
Gauge
PI–1
Outlet
Off
On
Vent
Inlet
Off
Low
Press
High
Press
0-15 PSI
Test Gauge
PI–2

JOB SHEET #1

Calibration Data Sheet

Technician's Name: ______________________ Title: ____________

Standard Used: ______________________

Manufacturer: ______________________ Serial #: ____________

Instrument Calibrated: ______________________

Manufacturer: ______________________ Serial #: ____________

Date: ______________________ Field ☐ Bench ☐

Nominal Pressure	True Pressure	Measured Pressure	Deviation
0	0		
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

Start Time ____________

Completion Time ____________

Comments

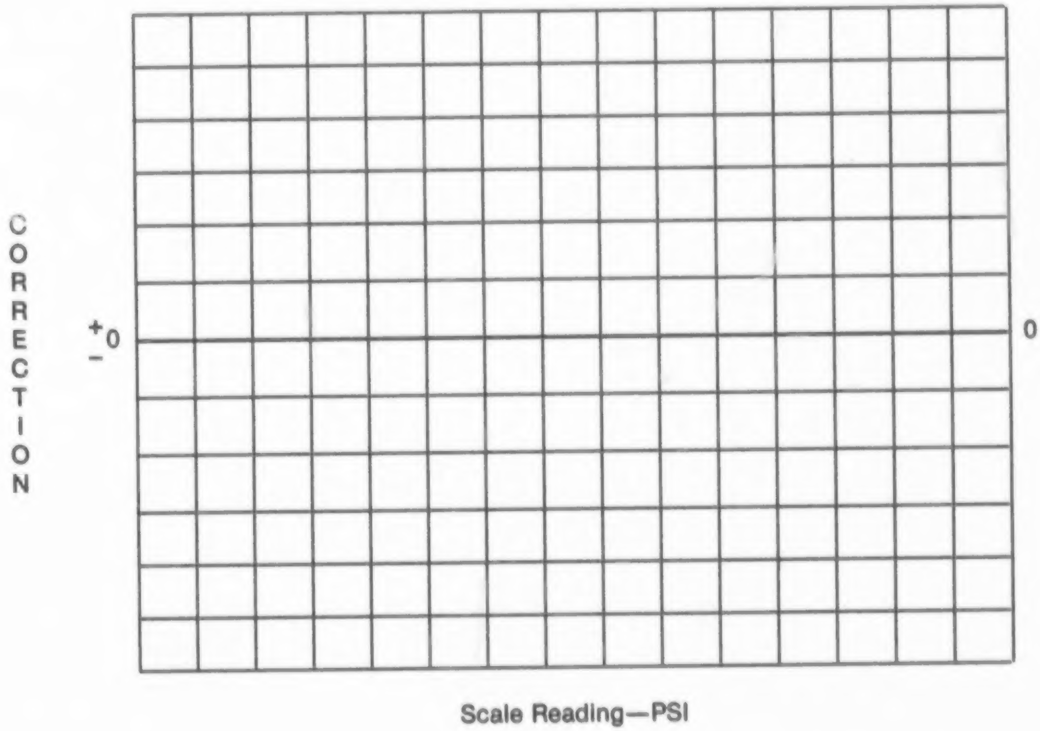
Prepare and attach a calibration curve to complete this data.

JOB SHEET #1

Calibration Curve

Prepared by: ______________________________ Date: ______________

Instrument Calibrated: ________________________ Serial #: ____________



CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

JOB SHEET #2 — CALIBRATE A TEST GAUGE WITH A HYDRAULIC DEADWEIGHT TESTER

A. Equipment and materials

1. Safety glasses
2. Hydraulic deadweight tester (Ametek, Mansfield Green T-50)
3. Instruction manual for selected deadweight tester
4. Test Gauge, 0-1000 psi, Ametek or equivalent 1404
5. Basic hand tools
6. Cotton gloves
7. Pencil
8. Jeweler's screwdriver

B. Routine #1 — Setting up and calibrating test equipment

1. Put on safety glasses, and leave them on.
2. Place equipment on a bench, and assemble as indicated in Figure 1 that accompanies this job sheet.
3. Make sure all connections are tight.
4. Check the zero of the Test Gauge.
5. Ask your instructor for the special tool required if you have to zero the Test Gauge.
6. Put on a pair of gloves before you handle the weights.
7. Add weights as required, and record the outputs for the Test Gauge at all pressures indicated on the Data Sheet that accompanies this job sheet.
8. Check the weights as you add them to make sure they spin freely, and if the weights do no spin freely, ask your instructor for help.
9. Continue testing until all pressures have been determined and entered on the data sheet.

   ☐ Have your instructor check your work.

JOB SHEET #2

10. Remove the weights, and place them back in the tester case.

11. Dismantle the rest of the test apparatus, and return all equipment to proper storage.

C. Routine #2 — Preparing a calibration curve

1. Calculate the deviation for each pressure reading on your data sheet.

   (NOTE: If you have a conversion factor for local gravity, you will want to multiply Nominal Pressures by the factor to get True Pressures, but if you are not working with a conversion factor for local gravity, assume that you are at sea level and that nominal and true pressures are equal.)

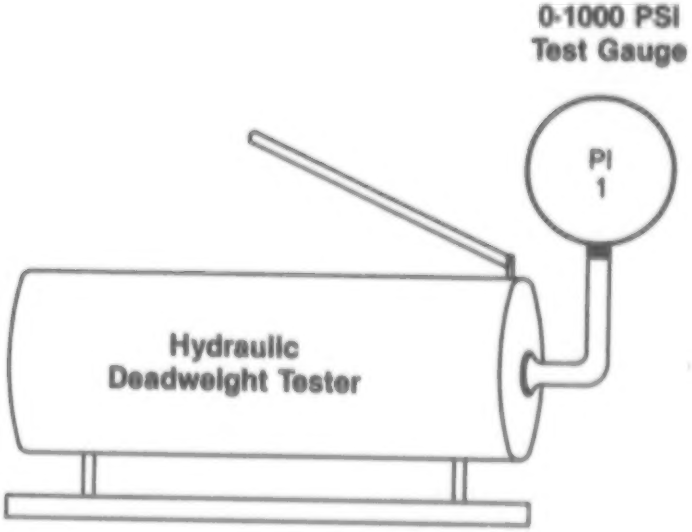
2. Use the deviation data to develop a calibration curve for the indicator and the test gauge.

   ☐ Have your instructor check your calibration curve.

3. Clean area, and return materials to proper storage.

JOB SHEET #2

FIGURE 1


0-1000 PSI
Test Gauge
PI
1
Hydraulic
Deadweight Tester

JOB SHEET #2

Calibration Data Sheet

Technician's Name: ______________________ Title: __________

Standard Used: ______________________________

Manufacturer: ______________________ Serial #: __________

Instrument Calibrated: ______________________________

Manufacturer: ______________________ Serial #: __________

Date: ______________________ Field ☐ Bench ☐

Nominal Pressure	True Pressure	Measured Pressure	Deviation
0	0	______	______
100	______	______	______
200	______	______	______
300	______	______	______
400	______	______	______
500	______	______	______
600	______	______	______
700	______	______	______
800	______	______	______
900	______	______	______
1000	______	______	______

Start Time

____

Completion Time

____

Comments ______________________________

____

____

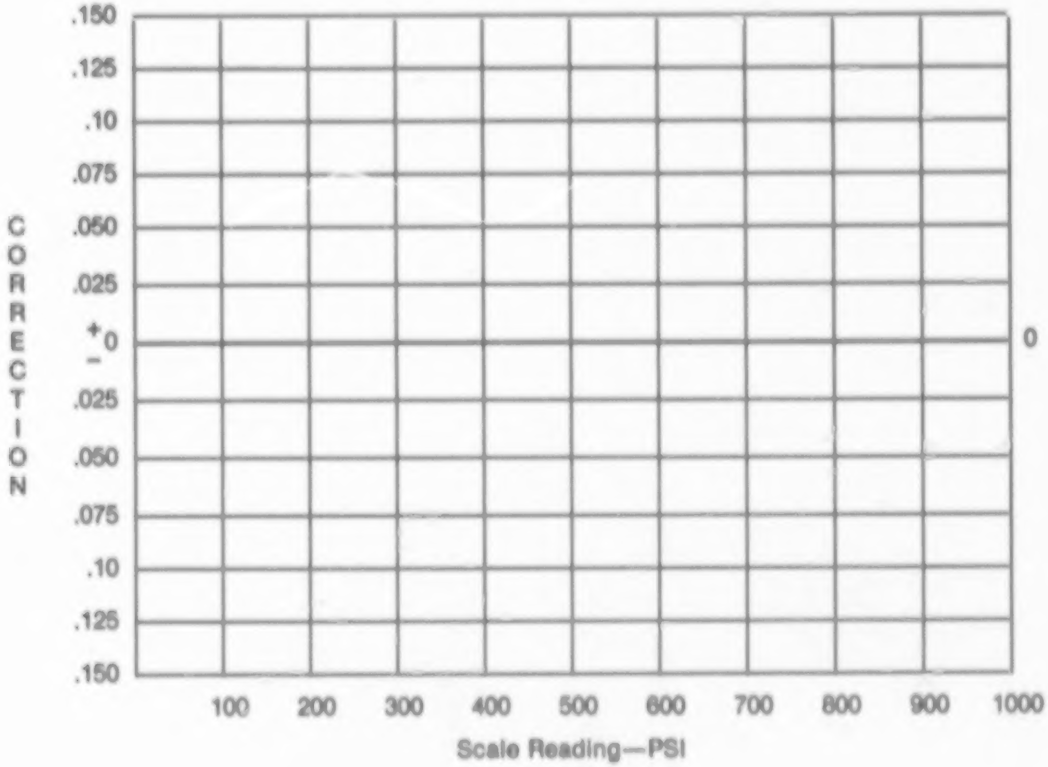
Prepare and attach a calibration curve to complete this data.

JOB SHEET #2

Calibration Curve

Prepared by: ______________________ Date: ____________

Instrument Calibrated: ______________________ Serial #: ____________



CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

PRACTICAL TEST #1
JOB SHEET #1 — CALIBRATE A TEST GAUGE WITH A PNEUMATIC DEADWEIGHT TESTER

Student's name ______________________________ **Date** ____________

Evaluator's name ______________________________ **Attempt no.** ______

Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Set up deadweight tester properly.	1.	☐	☐
2. Zeroed instruments properly.	2.	☐	☐
3. Calibrated test gauge properly.	3.	☐	☐
4. Completed Calibration Data Sheet.	4.	☐	☐
5. Completed calibration curve.	5.	☐	☐
6. Returned equipment to proper storage.	6.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #1 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another product must be submitted for evaluation.)

Criteria:				
Equipment Setup	Excellent 4	Acceptable 3	Fair 2	Poor 1
Data Entry	Complete 4	Acceptable 3	Poor 2	Incomplete 1
Calibration Curve	Well prepared 4	Acceptably prepared 3	Poorly prepared 2	Unacceptable 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ______________________________

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

PRACTICAL TEST #2
JOB SHEET #2 — CALIBRATE A TEST GAUGE WITH A HYDRAULIC DEADWEIGHT TESTER

Student's name ______________________________ **Date** ____________

Evaluator's name ____________________________ **Attempt no.** ______

> Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Set up deadweight tester properly.	1.	☐	☐
2. Zeroed instruments properly.	2.	☐	☐
3. Calibrated test gauge properly.	3.	☐	☐
4. Completed Calibration Data Sheet.	4.	☐	☐
5. Completed calibration curve.	5.	☐	☐
6. Returned equipment to proper storage.	6.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #2 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another product must be submitted for evaluation.)

Criteria:				
Equipment Setup	Excellent 4	Acceptable 3	Fair 2	Poor 1
Data Entry	Complete 4	Acceptable 3	Poor 2	Incomplete 1
Calibration Curve	Well prepared 4	Acceptably prepared 3	Poorly prepared 2	Unacceptable 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ______________________________________

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

TEST

NAME ____________________________ SCORE ______________

1. Match the terms on the right with their correct definitions.

_____a. A Paris based international standards agency that establishes metric standards

_____b. The official headquarters of the ISO metric system of weights and measures; it is based in Paris, France

_____c. The standard metric measures used world wide, and officially abbreviated SI

_____d. The official United States agency that establishes and maintains standards, including primary standards or replicas used in America

_____e. An international commission that sets and disseminates working electrical standards from its headquarters in Geneva, Switzerland

_____f. An industry/government sponsored agency in New York City that sets and disseminates standards information for the U.S.

_____g. A U.S. technical society that establishes process instrumentation standards in conjunction with NBS and industry

_____h. An American technical society that works with NBS and industry to establish electrical/electronic standards

_____i. An agency formed by insurance companies to set standards for fire safety, including wiring and instrumentation

_____j. A unit used in solid geometry to describe the angle in radians projected from the center of a sphere

1. ANSI
2. IEEE
3. NBS
4. NFPA
5. ISO
6. sr
7. IBWM
8. ISA
9. IEC
10. SI

TEST

2. Complete statements concerning calibration standards by circling the material that best completes each statement.

   a. There are **(six, seven)** international standards or physical measures from which all other measures are derived.

   b. The calibration measures are:

      1) **(Length, Distance)**

      2) **(Mass, Force)**

      3) **(Time, Rate)**

      4) **(Electricity, Static charge)**

      5) **(Temperature, Pressure)**

      6) **(Light, Opacity)**

3. Solve the following problems concerning standards for length by selecting the correct answers.

   a. The abbreviation for the SI unit for length is ft. or m?

      Answer: ______________________________

   b. What other standards are derived from the standards for length, weight and mass, or area and volume?

      Answer: ______________________________

4. Solve the following problems concerning standards for mass by selecting the correct answer.

   a. The abbreviation for the SI unit for mass is lb. or kg?

      Answer: ______________________________

   b. The original cylinder used for the mass standard is kept by the IBWM in Paris, but there is another exact duplicate housed in the facilities of ISA or NBS?

      Answer: ______________________________

   c. Other standards derived from the standards for mass include relative mass and volume or force in newtons and power in watts?

      Answer: ______________________________

TEST

5. Complete statements concerning standards for time by circling the material that best completes each statement.

   a. The SI unit for time is the (**minute, second**), abbreviated (**m, s**).

   b. The time unit is produced with a cesium clock by measuring the duration of 9,192,631,770 cycles of (**radiation, alternations**) from cesium under controlled conditions.

   c. The time standard is (**not reproducible, reproducible**) anywhere in the world because it is the result of natural phenomena, not a physical device stored at a location.

   d. A derived SI standard includes frequency or cycles per second in (**hertz, amps**).

   e. The frequency unit describes the number of transitions that an alternating waveform makes during a (**second, minute**).

   f. In conjunction with the meter unit, the time unit is also used to derive speed in (**meters, miles**) per second, and acceleration in (**meters, feet**) per second.

6. Solve problems concerning standards for electricity by selecting the correct answer.

   a. What is used to measure electrical flow, the ampere or the ohm?

   Answer: ____________

   b. What is the formula that finds a relationship between volts, amperes, and ohms, Ohm's law or The Amperage Law?

   Answer: ____________

7. Solve problems concerning standards for temperature by selecting the correct answer.

   a. The SI unit for temperature is shown in degrees K or °F?

   Answer: ____

   b. The SI unit for temperature has an absolute zero point which makes it easier to produce standards that can be what, easily referenced or reproduced anywhere?

   Answer: ____

TEST

8. Solve problems concerning standards for light by selecting the correct answer.

   a. The abbreviation for the SI unit for light is rds or cd?

   Answer: ______________________________

   b. The SI unit for light is found by measuring what, speed of a reflection or radiation from a source in a single direction?

   Answer: ______________________________

9. Select true statements concerning national standards by placing an "X" beside each statement that is true.

   (NOTE: For a statement to be true, all parts of the statement must be true.)

   _____a. Each nation has organizations such as the NBS in the U.S. that implement systems to comply with international standards.

   _____b. National standards assure that no matter where products are produced, as long as they are produced to standard measures, they will work with other products.

   _____c. Within the past ten years, metric measure has become commonly used in the U.S. because of an increased dependence on world trade, but use of metrics is troublesome and will probably die out.

   _____d. The National Bureau of Standards has laboratories in Washington, D.C., and in Boulder, Colorado.

   _____e. Overseeing standards is a task far too large for the NBS alone, and the government has delegated part of the job to a network of professional organizations to help in the generation of standards and the dissemination of information about standards.

   _____f. Organizations such as IEEE, ISA, NFPA, and ANSI have access to technical expertise from business, industry, and education, that the government cannot afford to maintain, and the cooperative arrangement between government and professional organizations frees the NBS to administer and coordinate widespread activities.

   _____g. The coordination makes it possible for all parts of society to have access to measures based on standards, and these standards are based on three different levels:

   1) Primary standards;

   2) Secondary standards;

   3) Ad-hoc standards.

TEST

10. Complete statements concerning primary standards by circling the material that best completes each statement.

    a. A primary standard is the initial test set-up, or a device to which all (**secondary standards, other standards**) trace their origin.

    b. Most primary standards are held by the (**IBWM, NBS**); however, occasionally, a major industry may be designated to be the primary source.

    c. All standards of a particular measure can be traced to the primary, and all other standards must be (**calibrated, recertified**) periodically to the primary.

11. Complete statements concerning secondary standards by circling the material that best completes each statement.

    a. Secondary standards are calibration devices entrusted to manufacturers, test and calibration laboratories, or (**calibrating agencies, local shops**).

    b. Secondary standards are directly traceable to primary standards, and are used only to calibrate (**working standards, other secondary standards**).

12. Complete statements concerning shop or working standards by circling the material that best completes each statement.

    a. The standards that manufacturers use to produce products, and the standards used by (**business, governments**) for commerce and trade are called shop or working standards.

    b. All shop or working standards are traceable to the primary standards by way of the secondary standards used by (**calibration service agencies, NBA**).

    c. Shop standards must be recalibrated (**often, every other year**) to maintain system integrity, and calibration records should be filed for reference.

    d. As a rule of thumb, a working standard such as a test gauge should have an accuracy (**ten, two**) times greater than the gauge or device it is used to test.

13. Complete statements concerning manufacturers' specifications by circling the material that best completes each statement.

    a. Manufacturers of process control systems and devices have specifications for their products, and these specifications (**are frequently needed, are essential**) for proper operation of equipment.

    b. Specifications appear in documents such as instruction books or equipment manuals, and deal with matters of equipment (**cost, design**) and equipment applications.

TEST

14. Select true statements concerning specifications for accuracy by placing an "X" beside each statement that is true.

_____a. Because accuracy is the heart of all measuring concerns in process instrumentation, it is an extremely important specification.

_____b. Accuracy expresses how close a measuring device comes to indicating the actual quantity being measured.

_____c. Accuracy is always measured with a shop standard and expressed as plus of minus (±) percent of full scale output.

15. Solve problems concerning specifications for sensitivity by selecting the correct answer.

a. Sensitivity specifications are important because they provide information about a system that is what, needed for evaluation or much too small for a human to detect?

Answer: ____

b. Sensitivity refers to the smallers measurement a control system can what, detect and act on, or control without interrupting the process?

Answer: ____

16. Basic true statements concerning specifications for repeatability by placing an "X" beside each statement that is true.

_____a. Repeatability expresses the ability of an instrument to produce the same result time after time from a given input in the same direction.

_____b. Repeatability is expressed as plus or minus (±) percent of span to express the maximum difference between output readings.

TEST

17. Solve the following problems concerning specifications for permanence by selecting the correct answer.

    a. Permanence may be called the useful life of an instrument because an instrument does what, wears out at a given point in time, or may wear to a point where accuracy and repeatability are not acceptable.

    Answer: ______________________________

    b. Another word for permanence is what, accuracy or durability?

    Answer: ______________________________

18. Select true statements concerning other parameters and applications by placing an "X" beside each statement that is true.

    _____a. Other than the four key specifications, user's manuals are rather limited.

    _____b. Installation instructions will contain considerations for special environmental controls for fire and explosion protection and other control requirements.

    _____c. Installation instructions seldom list limitations equipment may have with respect to location, application, and operating procedures.

19. Complete statements concerning deadweight testers by circling the materials that best complete each statement.

    a. A deadweight tester consists of a weight table mounted on a piston so that the weights placed on the table will cause the piston to apply **(weight, pressure)** to the oil reservoir as weight per square area of the piston.

    b. According to Pascal's principle, the fluid pressure in a closed system is distributed equally in all directions, so when a hydraulic device such as a gauge is attached to the reservoir, the pressure applied to the piston in pounds or kilograms can be used to **(calibrate the device, measure weight)**.

    c. A deadweight tester is complicated in that a hydraulic hand pump is required to balance the system, and the piston attached to the weight must be lubricated in some way to remove the **(influence of friction, prospect of contamination)**.

20. Solve problems concerning manometers by selecting the correct answer.

    a. Manometers are typically used to measure what, high or low pressures?

    Answer: ______________________________

TEST

b. Water and Mercury are common liquids used in manometers, and of the two, the liquid with the heaviest specific gravity is Mercury or water?

Answer: ____________________

c. A limitation of manometers is that they are subject to expansion and contraction in response to what, pressure changes or temperature changes?

Answer: ____________________

21. Select true statements concerning potentiometers by placing an "X" beside each statement that is true.

_____a. A potentiometer measures electrical pressure difference by measuring or metering voltage in a system.

_____b. A potentiometer is a variable resistor device used to divide a known voltage into a smaller increment that can be compared to another unknown small voltage from a sensor or transducer output.

_____c. Potentiometers are normally used to measure alternating current; however, if special indictive coils are used, a potentiometer can also measure direct current.

22. Solve problems concerning frequency meters by selecting the correct answer.

a. A frequency meter is used with what, an AC or a DC power source?

Answer: ____________________

b. If a frequency meter were connected across the output terminals of an ultrasonic generator, the readout of generator output would be in what, kHz or numeric form?

Answer: ____________________

c. A frequency meter will respond to almost any AC waveform or only to a sinewave?

Answer: ____________________

23. Select true statements concerning digital VOMs by placing an "X" beside each statement that is true.

_____a. A digital VOM measures and displays DC and AC electrical voltage, ohms, and milliamperes in numeric form.

_____b. Analog meters with swinging pointers were once favorite troubleshooting tools, but digital VOMs are more accurate, smaller, lower in cost, but not as rugged.

TEST

_____c. With the advent of high speed digital signals, the digital VOM has another distinct advantage because it can read a variable correctly, but an analog meter is limited to lower frequencies.

24. Select true statements concerning decade resistance boxes by placing an "X" beside each statement that is true.

_____a. A decade resistance box is a box of calibrated precision resistors which allows a user to switch a decade level of resistance with each switch.

_____b. In a decade resistance box, the decades are usually 1s, 10s, 100s, 1000s, 10000s, 100,000s, and finally, megaohms, and the box would have seven switches so that the user can select from 1 ohm to 10,999,999 ohms in one ohm steps.

_____c. The box is designed to provide technicians with the capability of duplicating any resistor value necessary to calibrate an electrical system or component.

_____d. Decade resistance boxes must be used with skill because the percentage of accuracy is less than the highest precision of the lowest precision part because the series arrangement creates a cumulative error problem in the total resistance of the box.

_____e. One way around the cumulative error problem is to use fewer decades which requires more boxes with different segments of the total resistance range.

25. Complete statements concerning thermal and ice baths by circling the material that best completes each statement.

a. The thermal bath is a device used in (**installing, calibrating,**) thermal sensors, transducers, and control devices.

b. The thermal bath is an (**insulated, open**) vessel that has a precision controlled temperature capability so that when it is filled with liquid the bath can provide the range of temperatures needed for calibrating thermal equipment.

c. Some thermal baths are designed almost as simple as a (**thermometer, thermos bottle**), but they range up to expensive units with programmable precision temperature ranges that are computer controlled.

d. Ice baths are designed to maintain liquid used in a test at the temperature of (**melting ice, frozen ice**).

26. Solve problems concerning thermometers by selecting the correct answer.

a. A thermometer made of stress-relieved pyrex glass and precisely manufactured and tested is considered what, an industrial-grade thermometer or a calibration-grade thermometer?

Answer: ____

TEST

b. The precision case in which a thermometer is mounted helps protect the glass in the thermometer, but it also serves to what, make the thermometer easier to mount or make the scale easier to read?

Answer: ______________________________

27. Select true statements concerning oscilloscopes by placing an "X" beside each statement that is true.

_____a. The high frequency, precision, portable oscilloscope is rapidly becoming the instrument preferred by technicians because it is easy to use, and gives much more information than other instruments.

_____b. An oscilloscope receives electrical signals, and displays them on a video screen as a plot of voltage in the horizontal direction, and time in the vertical direction.

_____c. Measuring electrical quantities with a standard meter leaves a chance for error, but an oscilloscope permits a technician to watch the dynamic action of a system, and actually see the problem.

_____d. Some oscilloscopes have memory so that two or more pieces of information can be stored and retrieved later for evaluation.

_____e. Some oscilloscopes can produce a hard-copy printout, and other oscilloscopes can be interfaced with a computer/printer to provide printouts.

28. Complete statements concerning pneumatic calibrators by circling the materials that best completes each statement.

a. A pneumatic calibrator is a portable test instrument used to troubleshoot and calibrate (**pneumatic devices, pneumatic and hydraulic devices**).

b. Pneuamatic calibrators are used for bench testing, but can also be used for field calibration so that a technician will not have to remove equipment and (**take it back to the shop, replace it before testing**).

c. Some pneumatic calibrators are available with their own internal air supplies, 24 or 48v DC power supplies, and (**digital readouts, printouts**).

29. Select true statements concerning precision power and current supplies by placing an "X" beside each statement that is true.

_____a. Precision power supplies provide voltages and currents used in calibration.

_____b. Voltage sources usually have some range of output voltage adjustable to test requirements, and a very small tolerance for error in voltage, sometimes as low as zero percent.

TEST

_____c. Voltage sources also have a system for detecting and protecting the power supply from severe load changes, and current limits can usually be set on these instruments.

_____d. Current sources provide precision, constant current outputs set to the test requirements, and held within a close tolerance of 1% or better.

_____e. Current sources are limited by their slow recovery time from changes in the load.

30. Solve problems concerning calibration tools and materials by inserting the word(s) that best completes each statement.

    a. Basic hand tools a technician should carry an assortment of screwdrivers and combination wrenches, and a tool for cutting wires, stripping insulation and crimping connections; this tool is called ____________ ____________ ____________ ____________ ____________ ____________.

    b. For troubleshooting and calibration, a technician should carry what for measuring amps and ohms? ____________ ____________

    c. Some materials are flammable and should be used with care and properly stored; what kind of materials are these? ____________ ____________

    d. What should a technician wear when working around any kind of equipment? ____________ ____________

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

31. Demonstrate the ability to:

    a, Calibrate a test gauge with a pneumatic deadweight tester. (Job Sheet #1)

    b. Calibrate a test gauge with a hydraulic deadweight tester. (Job Sheet #2)

CALIBRATION STANDARDS AND TEST EQUIPMENT
UNIT II

ANSWERS TO TEST

1. a. 5
   b. 7
   c. 10
   d. 3
   e. 9
   f. 1
   g. 8
   h. 2
   i. 4
   j. 6

2. a. Six
   b. 1) Length
      2) Mass
      3) Time
      4) Electricity
      5) Temperature
      6) Light

3. a. m
   b. Area and volume

4. a. kg
   b. NBS
   c. Force in newtons and power in watts

5. a. Second, s
   b. Radiation
   c. Reproducible
   d. Hertz
   e. Second
   f. Meters, meters

6. a. The ampere
   b. Ohm's law

7. a. Degrees K
   b. Reproduced anywhere

8. a. cd
   b. Radiation from a source in a single direction

ANSWERS TO TEST

9. a, b, d, e, f

10.
    a. All other standards
    b. NBS
    c. Recertified

11.
    a. Calibrating agencies
    b. Working standards

12.
    a. Business
    b. Calibration service agencies
    c. Often
    d. Ten

13.
    a. Are essential
    b. Design

14. a, b, c

15.
    a. Much too small for a human to detect
    b. Detect and act on

16. a, b

17.
    a. May wear to a point where accuracy and repeatability are not acceptable
    b. Durability

18. b, d

19.
    a. Weight
    b. Calibrate the device
    c. Influence of friction

20.
    a. Low pressure
    b. Mercury
    c. Temperature changes

ANSWERS TO TEST

21. a, b

22. a. AC
    b. Numeric form
    c. Almost any AC waveform

23. a, c

24. a, b, c, d, e

25. a. Calibrating
    b. Insulated
    c. Thermos bottle
    d. Melting ice

26. a. A calibration-grade thermometer
    b. Make the scale easier to read

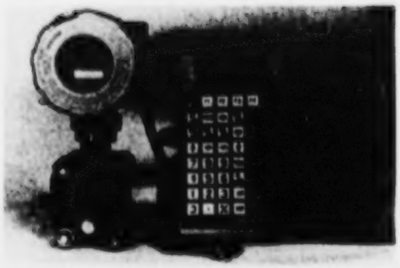
27. a, c, d, e

28. a. Pneumatic devices
    b. Take it back to the shop
    c. Digital readouts

29. a, c, d

30. a. An electrician's 6-in-1 tool
    b. A DVOM
    c. Cleaning materials
    d. Safety glasses

31. a. Evaluated according to criteria in Practical Test #1
    b. Evaluated according to criteria in Practical Test 32



TRANSDUCERS AND TRANSMITTERS

UNIT III

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss transducers and transmitters and their applications for sensing and transmitting process information. The student should also be able to list the characteristics of bourdon tubes, diaphragms, capsules, and bellows, and other devices that function in measuring systems. The student should also be able to troubleshoot and calibrate transducers/transmitters commonly found in process systems. These competencies will be evidenced by correctly completing the procedures outlined in the job sheets, and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to transducers and transmitters with their correct definitions.
2. Select true statements concerning pressure transducers.
3. Arrange in order the steps in the operation of a bourdon tube.
4. Differentiate between spiral and helical bourdon tubes.
5. Solve problems concerning how diaphragms, capsules, and bellows work.
6. Select true statements concerning piezoelectric crystals.
7. Solve problems concerning conversion to usable form.
8. Complete statements concerning LVRs (linear variable resistors) and potentiometers.
9. Select true statements concerning LVDTs (linear variable differential transformers).
10. Select true statements concerning variable capacitance/variable frequency systems.
11. Select true statements concerning mechanical to pneumatic pressure transmitters.
12. Solve problems concerning indicators.

OBJECTIVE SHEET

13. Complete statements concerning pressure transmitters.
14. Solve problems concerning calibrating differential pressure transmitters.
15. Complete statements concerning calibrating differential pressure transmitters.
16. Solve problems concerning level transmitters.
17. Match types of level sensors with their characteristics.
18. Solve problems concerning calibrating level transmitters.
19. Select true statements concerning troubleshooting level transmitters.
20. Match temperature sensors with their characteristics.
21. Select true statements concerning types of temperature transmitters.
22. Solve problems concerning calibrating temperature transmitters.
23. Select true statements concerning flow sensors/transmitters.
24. Complete statements concerning vortex shedding flowmeters.
25. Select true statements concerning ultrasonic flowmeters.
26. Select true statements concerning turbine flowmeters.
27. Solve problems concerning calibrating vortex and ultrasonic flow units.
28. Solve problems concerning troubleshooting flow instrumentation.
29. Demonstrate the ability to:
    a. Calibrate and test a differential pressure transmitter. (Job Sheet #1)
    b. Pre-test, calibrate, and post-test a pneumatic pressure transmitter. (Job Sheet #2)
    c. Field service a temperature transmitter. (Job Sheet #3)

TRANSDUCERS AND TRANSMITTERS
UNIT III

SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information sheet.

C. Make transparency.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Invite the supervisor of a local or area processing activity to talk to the class about the type of transducers and transmitters used in an area industry.

G. Have available devices to show students as you discuss various sensor/transmitter devices in class.

H. Discuss and demonstrate the procedures in the job sheets.

I. In the event a pneumatic calibrator is not available for the job sheets in this unit, pneumatic pressure regulators and high-accuracy test gauges may be substituted. However, any modifications in equipment or procedure should be checked prior to student performance to assure that the apparatus is safe and that the modification will retain the accuracy required for the objective.

J. Give test

REFERENCES USED IN DEVELOPING THIS UNIT

A. *Instrumentation Maintenance, Module 3, Pneumatic Transducers, Computing Relays*. Research Triangle Park, NC 27709: Instrument Society of America, 1981.

B. *Instructions, Differential Pressure Transmitter 392T, 393T, 394T, 397T, and 398 Model A*. Rochester, NY 14692-0110: Taylor Instrument, a Division of Combustion Engineering, Inc., 1984.

C. *Instruction Book 2096, 11GM Series Pressure Transmitter Styles C and D*. Foxboro, MA: 02035: The Foxboro Company, 1979.

D. *Service Instructions, Model 40 Nullmatic ® Pressure Regulators*. Spring House, PA 19477: Moore Products Co., 1982.

TRANSDUCERS AND TRANSMITTERS
UNIT III

INFORMATION SHEET

I. **Terms and definitions**

A. Transmitter — A process instrument that accepts sensor output and converts it into a standard electrical or pneumatic process signal which is transmitted to an indicator, recorder, controller, or other device

B. Electrical standard signal — The most common electrical current signal, 4-20 mA, used to transmit process information

C. Pneumatic standard signal — The most common air pressure signal, 3-15 psi and 20-100 kPa, used to transmit process information.

D. Sensor — A device that detects the presence of, and measures the value of a given physical phenomena used in process control

E. Transducer — A sensor device that converts a measures phenomena from one form of energy to another

II. **Pressure transducers**

A. Pressure transducers are devices that sense or detect pressure, and determine the amplitude of the force applied.

B. Pressure transducers also convert detected pressure into another energy form, usually pneumatic or electrical, for transmission to a readout or controller.

C. There are many ways to sense or detect pressure, but the most common systems employ:

1. Manometers
2. Bourdon tubes
3. Bellows
4. Piezoelectric crystals
5. Diaphragms
6. Capsules

D. The basic manometer is a "U" tube device or a well type measuring device.

(NOTE: Manometers have been discussed earlier, and characteristics of other devices to sense or detect pressure are expanded in following objectives.)

INFORMATION SHEET

III. How bourdon tubes work

A. The bourdon tube with its 270 degree "C" element is brazed into a socket that can be attached to a pressure source while the other end of the tube is plugged into a tip that has an attachment hole where a link is fastened.

B. The link connects with a gear/arm mechanism that turns a pinion which is part of a bearing-mounted shaft.

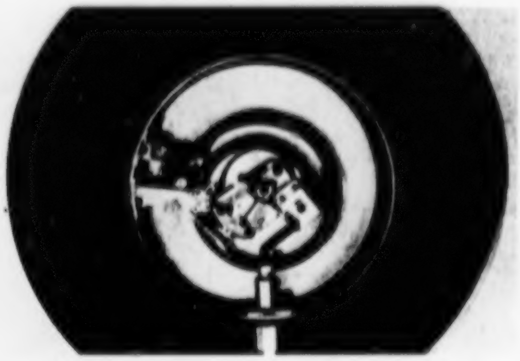
C. The bearing-mounted shaft runs the gauge pointer or control device.

D. Pressure received at the socket is routed to the flattened tube, and causes the "C" shaped tube to attempt to straighten, and this results in movement of the tip away from the center.

(NOTE: Negative pressure will produce the opposite result, and the tip will move toward the center.)

E. Tip movement pulls or pushes the link, rotates the pinion shaft, and moves the tip of the gauge or the controller mechanism so that pressure is converted or transduced into mechanical motion. (Figure 1)

FIGURE 1



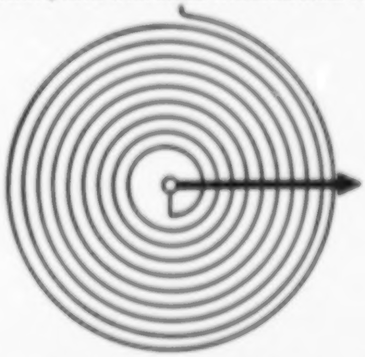
IV. Spiral and helical bourdon tubes

A. Since basic bourdon tubes have limited motion ability, spiral and helical tubes were invented to extend the movement of the gauge for special applications.

INFORMATION SHEET

B. The spiral tube is essentially a number of bourdon tubes connected end to end to multiply tube action, and increase mechanical movement. (Figure 2)

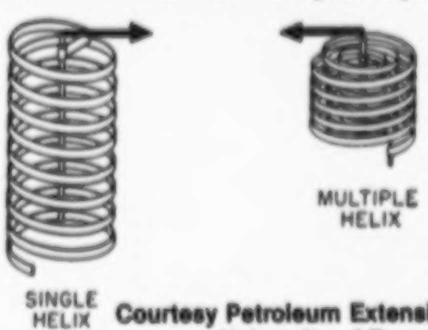
FIGURE 2



Courtesy Petroleum Extension Service (PETEX)
University of Texas at Austin

C. The helical tube is made of extra thick tubing for high pressure applications. (Figure 3)

FIGURE 3



Courtesy Petroleum Extension Service (PETEX)
University of Texas at Austin

V. How diaphragms, capsules, and bellows work

A. A diaphragm is the root device of both capsules and bellows, and is used for several pressure sensing applications.

B. A basic diaphragm is a thin piece of metal or plastic mounted in a solid frame that seals it and prevents it from leaking when pressure is applied.

INFORMATION SHEET

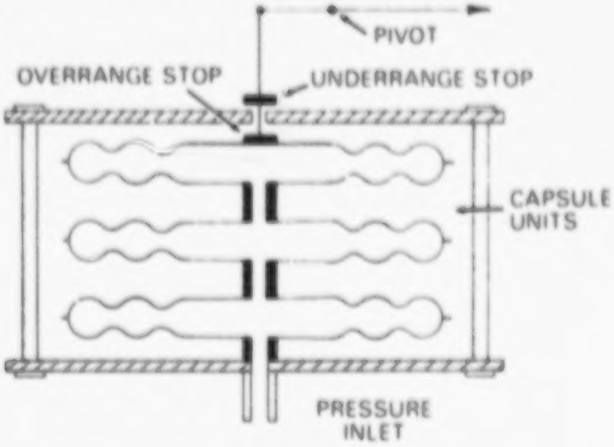
C. When pressure is applied to an inlet hole in the diaphragm frame or container, the diaphragm will be pushed out (positive) or pulled in (negative) depending on the application of positive or negative pressure. (Figure 4)

FIGURE 4

D. A capsule is two or more diaphragms sealed together at their circumferences, and pressure is applied to the area between the diaphragms through one or both sides.

E. A capsule can initiate more mechanical movement than a single diaphragm because the total deflection of a capsule is directly proportional to the number of diaphragms in the capsule. (Figure 5)

FIGURE 5



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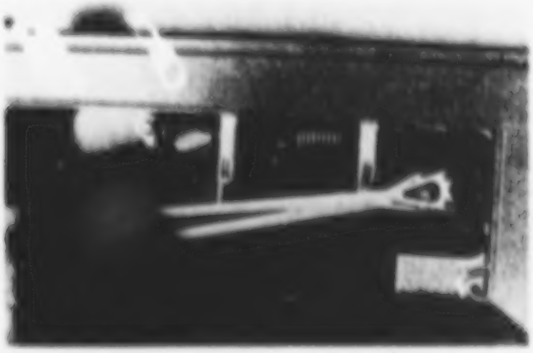
INFORMATION SHEET

F. A bellows is made by deforming a thin wall cylinder into alternate large diameter/small diameter sections, or a bellows can be formed with two or more capsules fastened together at their centers. (Figure 6)

FIGURE 6



G. As pressure is applied to a bellows, the small diameter sections enlarge and the large diameter sections shrink, and since this changes the size of the bellows, there is a direct relationship between pressure applied and the length of the bellows.

H. Bellows are used in applications where increased movement and mechanical drive are required.

VI. **Piezoelectric crystals**

A. A piezoelectric crystal is a combination sensor/transducer because it senses pressure applied on the crystal, and generates electrical pressure or voltage as an output.

B. The crystal is placed in a pressure tight vessel, and pressure is applied to the crystal or to a diaphragm attached to the crystal so that the crystal will be compressed in relation to applied pressure.

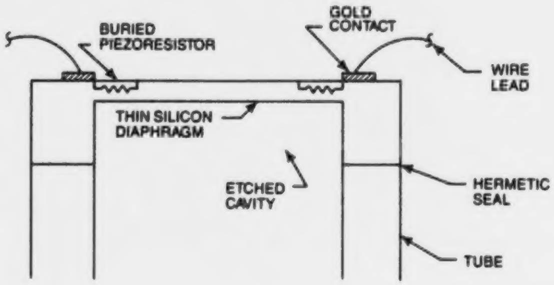
C. Compression causes a crystal to produce DC voltage at opposite ends of the crystal, and electrical leads attached to each end of the crystal connect to the output conductors.

D. When application demands, a diaphragm may be attached to the crystal to protect it from chemical reaction, and the diaphragm can supply mechanical advantage.

INFORMATION SHEET

E. Piezoresistive sensors are devices which produce changes in resistance in response to changes in pressure. (Figure 7)

FIGURE 7


BURIED PIEZORESISTOR
GOLD CONTACT
WIRE LEAD
THIN SILICON DIAPHRAGM
ETCHED CAVITY
HERMETIC SEAL
TUBE

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VII. Conversion to usable form

A. When a sensor is not a natural transducer, or if it produces a form of energy not suitable for transmission, the output must be converted.

B. Since most pressure sensors produce mechanical output, the most common conversions are:

1. Mechanical to pneumatic.

2. Mechanical to electrical.

VIII. Linear variable resistors (LVRs) and potentiometers

A. Linear variable resistors convert mechanical output into voltage or current output.

B. The mechanical output is connected to the movable contact on an LVR, and the mechanical movement changes the position of the movable contact.

INFORMATION SHEET

C. Change of the movable contact causes a resistance change in proportion to the pressure of the mechanical output.

D. An LVR device can be connected as a potentiometer to vary voltage output, or as a rheostat to vary current output.

IX. **Linear variable differential transformers (LVDTs)**

A. An LVDT is a three-winding transformer with two identical output windings cross-connected, and wound on each side of a primary input winding.

B. The primary and secondary coils are wound around a movable core whose movement determines output.

1. When the movable core is centered, the two secondary output coils produce identical voltage output, and since the secondary coils are cross-connected, the voltages cancel each other.

2. When the core moves in one direction or the other, one secondary loses output voltage, and the other secondary produces an AC output voltage in proportion to the change.

3. When the core moves in the opposite direction, the voltage is produced from the other secondary output coil.

C. Since the phase (AC waveform output timing) is opposite for each output coil, the LVDT will produce an AC output that has amplitude (output voltage) and phase that are proportional to the movement of the core.

D. When the core is connected to the mechanical output of the pressure device, the signal from the LVDT can produce an output that yields both direction and distance information in the form of phase and amplitude. (Figure 8)

INFORMATION SHEET

FIGURE 8

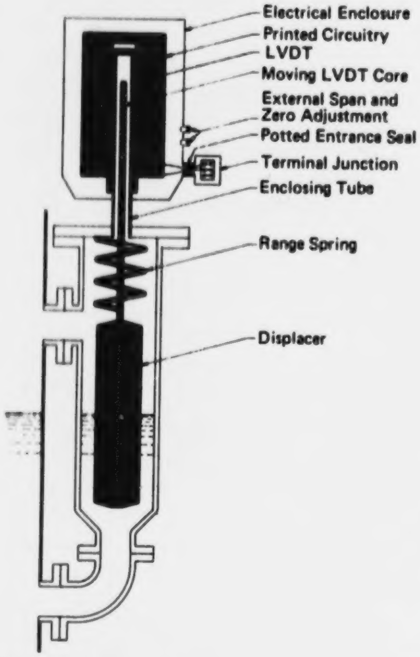

Electrical Enclosure
Printed Circuitry
LVDT
Moving LVDT Core
External Span and Zero Adjustment
Potted Entrance Seal
Terminal Junction
Enclosing Tube
Range Spring
Displacer

Figure supplied courtesy Magnetrol International

X. Variable capacitance/variable frequency systems

A. Since many control devices are digital, they can utilize frequency information directly without analog to digital conversion.

B. When converting mechanical movement to frequency changes, the mechanical output is connected to a variable capacitor which produces capacitance change in proportion to the mechanical movement produced by pressure output.

C. The capacitor is connected in a variable oscillator circuit as the frequency determining part of the system, so that when the capacitance changes due to mechanical/pressure changes, it causes the AC output frequency to change in proportion to the pressure.

D. Since the oscillator frequency is usually high, the AC output can be effectively transmitted some distance.

XI. Mechanical-to-pneumatic pressure transmitters

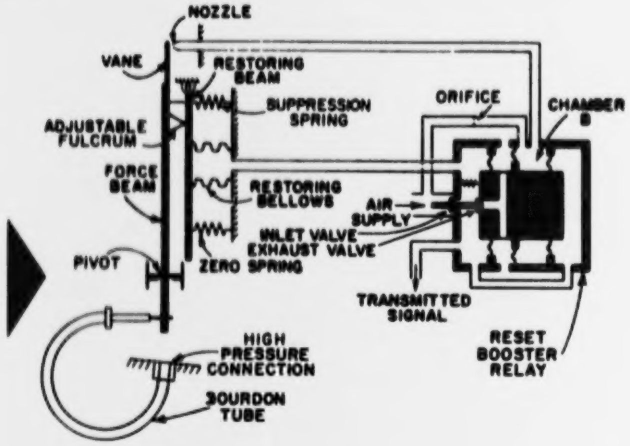
A. Converting mechanical output into pneumatic pressure for transmission is often accomplished with a mechanical flapper that moves in front of a nozzle that has air blowing from it.

INFORMATION SHEET

B. In a pneumatic pressure converter, supply air flows through a fixed restriction to a nozzle so that if the flapper moves toward the nozzle, air flow is cut off or reduced, and air pressure across the restriction is lowered.

C. The system produces a variable air pressure output which is proportional to the mechanical input. (Figure 9)

FIGURE 9


NOZZLE
VANE
RESTORING BEAM
SUPPRESSION SPRING
ORIFICE
CHAMBER B
ADJUSTABLE FULCRUM
FORCE BEAM
RESTORING BELLOWS
AIR SUPPLY
INLET VALVE
EXHAUST VALVE
PIVOT
ZERO SPRING
TRANSMITTED SIGNAL
HIGH PRESSURE CONNECTION
RESET BOOSTER RELAY
BOURDON TUBE

Courtesy Bailey Controls Company

XII. Indicators

A. Indicators provide a means to monitor a single parameter or multiple parameters in a system.

EXAMPLE: A pressure gauge provides an indication of pressure, and a sight glass is commonly used to provide an indication of level.

B. Indicators can also be part of another device such as a recorder or controller.

C. Indicators may be pneumatic, electrical, or digital depending on system requirements.

XIII. Pressure transmitters

A. Pressure transmitters receive input from a pressure source, and convert the signal to a form compatible with other system devices.

B. A pneumatic pressure transmitter monitors pressure input and converts it to the 3-15 psi output or other pneumatic standard.

INFORMATION SHEET

C. An electric pressure transmitter monitors pressure input and converts it to a 4-20 mA output or other electrical or digital standard.

XIV. **Differential pressure transmitters**

A. A ΔP transmitter receives input from two pressure sources, and gives an output equal to the difference of the two inputs.

B. ΔP transmitter outputs are pneumatic, electrical, or digital depending on their applications.

C. ΔP transmitters are used with orifice plates, pitot tubes, venturi tubes, and other devices to infer flow.

XV. **Calibrating ΔP transmitters**

A. Because ΔP transmitters monitor critical parameters in a system, they should be calibrated at regularly scheduled intervals.

B. Calibration data should always be completed, and a correctly plotted calibration curve may also be required.

XVI. **Level transmitters**

A. Level transmitters have two distinct parts:

1. A sensor element
2. A transducer/transmitter

B. Level transmitters are classed by their method of sensing liquid level which include:

1. Floats
2. Displacers
3. Capitance probes
4. Conductance probes
5. Static head/pressure differential
6. Infrared
7. Ultrasonic

INFORMATION SHEET

XVII. Types of level sensors and their characteristics

(NOTE: For more information on level sensors, review Unit IV, "Principles of Level Measurement," in MAVCC's *Introduction to Instrumentation*.)

A. Floats:

1. Hollow metal or plastic objects that ride on the level interface.
2. Attached to a measuring device by a cable or tape, and may ride up and down in a stilling well.

B. Displacers:

1. Hollow metal objects that output mechanical force because they displace liquid rather than ride on the liquid interface.
2. They are coupled to a measuring system via a shaft or tube, and are normally sealed from the liquid being measured by a packless metal seal.

C. Capacitance probes:

1. In principle, capacitance probes are two plates of a capacitor, and the liquid is the dielectric material between the plates that causes the devices to produce capacitance.
2. The capacitor is connected into an oscillator circuit whose output frequency changes with a change in liquid level.
3. The devices interface well with electrical output transmitters because the action of the probes is an electrical parameter.

D. Conductance probes:

1. Simple devices that depend on the measured liquid being an electrical conductor.
2. Electrical probes are placed in a vessel at points where level measurement is desired.
3. When liquid reaches the probes, current flows, and the present level is logged by the system.
4. Knowing where level is at any place in a vessel requires installation of probes at each level increment.

INFORMATION SHEET

E. Static head sensors

1. Static head is the pressure exerted by the height of a liquid in a vessel as measured by a pressure sensor at the bottom of the vessel.

2. In this instance, static head means that the vessel is open to atmosphere.

3. With a closed vessel, the pressures at the top and bottom must be compared by a measuring device.

XVIII. Calibrating level transmitters

A. Whether pneumatic or electrical, the most important points in calibrating level transmitters are:

1. Zero point

2. Linearity

3. Span

B. Calibration must begin with some provision to simulate the sensor output to the transmitter.

C. Manufacturers provide calibration documents with equipment, and the procedures outlined should be followed to the letter.

(NOTE: Step by step procedures for calibrating level transmitters are presented in the job sheets with this unit.)

D. Instruments used in calibrating must themselves be in calibration, and calibration instruments should be checked on a schedule as recommended by the manufacturer; the name of the tester, type of test, and date of test should be indicated on a calibration data sheet.

E. Calibrating any instrument with a standard that has not been recently certified is a waste of time.

XIX. Troubleshooting level transmitters

A. Always check the manufacturer's literature for specific problems, but use systematic troubleshooting procedures as required.

B. Make sure the instrument is properly installed because position, orientation, and placement are critical to level transmitters.

INFORMATION SHEET

C. Verify that the instrument is appropriate for the type and range specified for the installation.

EXAMPLE: It would be inappropriate to place an instrument on line and expose it to materials or environment in which it could not operate for any length of time.

D. When you don't know what the problem is, run the calibration tests, and the trouble will probably occur during the tests.

E. Visual checks will show damaged or burned parts of electrical instruments, and mechanical damage on any system can usually be spotted with a visual check.

F. Substituting a good unit for a suspected faulty one is a good procedure, and some instruments subsystems can be swapped to see if the fault follows the module from one part of the system to another.

G. If none of the tests isolate the problem, review the system to see what other part of the equipment may be causing the part in question to fail.

EXAMPLE: When a module works on the test bench but fails in the system, it could be an interface problem, or an improper signal sent by another part of the system that seems to be operating properly.

H. In electrical systems, the root problem may be several stages away from the apparent problem.

I. In troubleshooting it is very important to understand the entire system, and that includes mechanical, pneumatic, and electrical/electronic subsystems.

XX. Temperature sensors and their characteristics

(NOTE: For more information on temperature sensors, review Unit V, "Principles of Temperature Measurement," in MAVCC's *Introduction to Instrumentation*.)

A. Thermocouples:

1. These sensing devices cover temperature ranges commonly used in process applications, and have a wide range of applications because they are simple, rugged, and low cost.

2. These devices need no power supply because they generate a mV signal.

INFORMATION SHEET

B. RTDs (resistance-temperature detectors):

1. These devices are very linear and sensitive, and are usually made from fine wire and connected into a wheatstone bridge circuit in a fashion that produces accuracy as well as linearity.

2. RTDs are not generators and do require external circuitry and power supplies.

C. Thermistors:

1. These devices are thermal resistors made of metal oxides and semiconductor materials to operate as negative temperature coefficient devices.

2. These devices are low cost, and can be manufactured in almost any shape.

3. Thermistors are not linear, and do require external circuitry for power, measuring, and linearization.

D. Filled-thermal systems:

1. These are material expansion devices (an outgrowth of the liquid-in-glass thermometer) that can be operated with liquid, vapor, or gas principles.

2. Most configurations have a bulb, a capillary, and a bourdon tube or bellows actuator, and each configuration has distinct ranges, advantages, and limitations.

3. With temperature change, the liquid, gas, or vapor expands or contracts to create a pressure that is transmitted through the capillary to the actuator which produces mechanical motion to drive the transmitter.

XXI. Types of temperature transmitters

A. In general, thermocouples, RTDs, and thermistors are used with electrical transmitters, and filled-thermal systems are used with pneumatic transmitters.

B. Electrical transmitters used with thermocouples receive the millivolt signals produced by the sensor, and convert it into a 4-20 mA signal.

C. Pneumatic transmitters accept the output from a filled-thermal device or other mechanical device and convert the mechanical motion into a 3-15 psi or 20-100 kPa signal.

INFORMATION SHEET

D. Pneumatic systems are usually force balance systems where the initial pressure change acts on a bellows or diaphragm, and moves a mechanical lever that changes the relationship between a flapper/nozzle or similar device.

E. The change in relationship causes a change in pressure drop across a restrictor which moves an air amplifier to produce the 3-15 psi signal.

F. The signal is then sent back to the original level by way of a pneumatic bellows which restores the balance in the system.

XXII. Calibrating temperature transmitters

A. Electrical systems signals can be simulated with a precision power supply that produces the voltage or currents necessary to reproduce the sensor output to the input of the transmitter.

B. If the sensor and transmitter have to be calibrated, the actual temperature must be produced on a test bench where the zero temperature can be produced by a thermal bath, calibrated oven, or temperature calibrator.

C. All temperature tests are run up and down scale and repeated a specified number of times to insure accuracy and precision.

D. Since temperature changes occur slowly, when sensors are changed from one bath to another, the technician must wait until the temperature has stabilized.

XXIII. Flow sensors/transmitters

A. Most flow measurements are made by using differential pressure across a restriction in a pipe where material flow is monitored.

B. Devices such as orifice plates, flow nozzles, and venturi tubes are by far the most common flow measuring systems used by industry.

C. In common flow measuring systems, the ΔP transmitter is normally used to measure differential pressure, and should be calibrated on a regular schedule.

D. Newer electronics-based equipment uses systems such as vortex shedding flowmeters, ultrasonic flowmeters, transit time systems, and turbine flowmeters.

XXIV. Vortex shedding flowmeters

A. Vortex shedding flowmeters are so named because in a section of pipe they have a shedding element that disturbs the flow, and creates circular currents called vortices which are shed in the proximity of the element.

B. The frequency of the vortex shedding is directly proportional to flow.

INFORMATION SHEET

C. A sensor detects vortex shedding and generates an electrical impulse which goes on to a signal amplifier/conditioning transmitter.

D. The output from the conditioning transmitter is equal to flow.

XXV. Ultrasonic and Doppler flowmeters

A. Doppler systems and transit time systems both have high frequency sound transmitters and receivers that are housed separate, except some Doppler systems house the devices in the same case.

B. The transit time system is the simpler of the two systems, and its transmitter (ultrasonic transducer) is a man-made crystal driven by an electronic oscillator which is also synchronized with the detection circuitry.

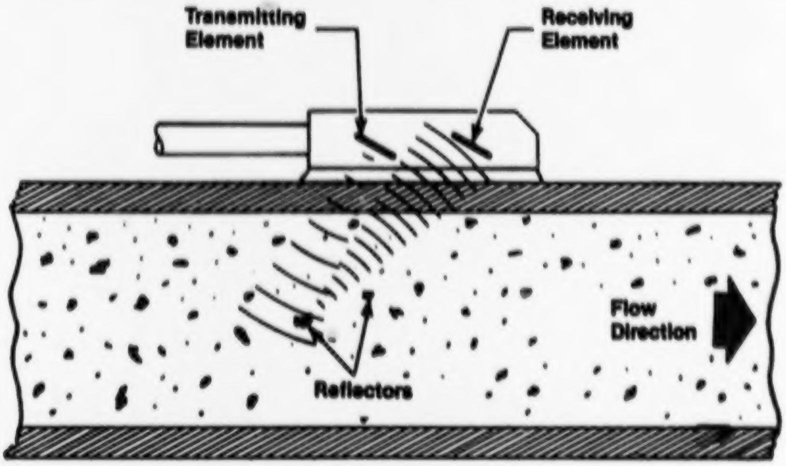
C. The transit time system receiver is also a crystal detector which feeds the incoming frequency to the detection-and-comparison circuitry where the comparison will yield the difference in time, and the time difference is converted to flow rate.

D. In ultrasonic flowmeter systems, the velocity of the sound waves will increase in the direction of flow, and decrease in the opposite direction, and the changes in flow rate and sound velocity are proportional.

E. Ultrasound flow measurement is always dependent upon the fluid containing some entrained material in the flow, such as a fluid with bubbles in it.

F. Doppler systems have equipment similar to transit time systems, oscillators to drive the transmitter, crystal transducers, an ultrasonic receiver, phase comparison circuitry, and control circuitry. (Figure 10)

FIGURE 10



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INFORMATION SHEET

G. In the doppler system, the ultrasonic signal is transmitted into the pipe of flowing liquid where the signal frequency and phase are shifted in proportion to the velocity of the flowing fluid.

H. The material suspended in the flow reflects and returns the signal to the receiver where a detector transduces the signal back to an AC electrical signal.

I. The AC signal is then compared with the original signal to produce a signal that can be converted to flow rate.

XXVI. Turbine flowmeters

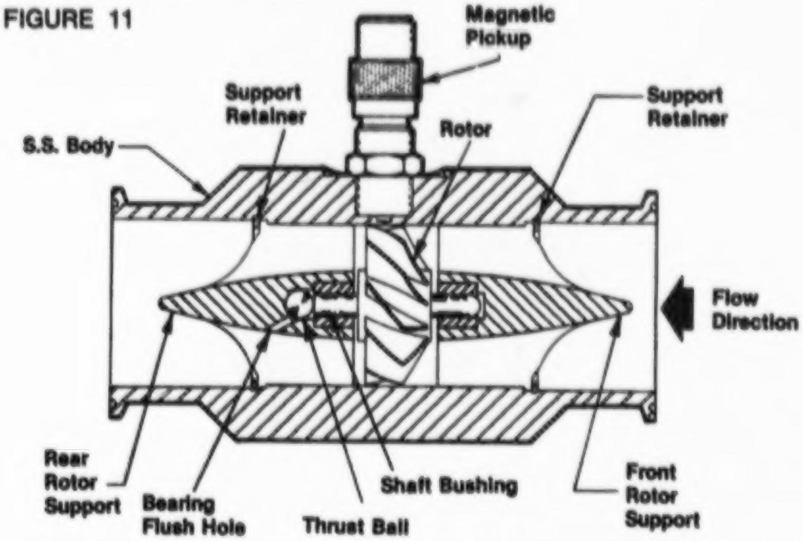
A. Turbine flowmeters are combination mechanical-electrical flow metering systems, and the turbine itself is a rotary blade instrument that fits into the pipe and turns at a speed dependent on the flow rate of fluid through the blades.

B. The rate of rotation can be picked up by a magnetic pick-up coil-type transducer, or rotation rates can be transferred by gear and cable or shaft to the outside of the pipe.

C. The frequency of rotation can be used to produce flow rate on an indicator, or it can be transmitted to another location.

D. When the frequency of rotation is to be transmitted, the pulse pick-up coil-type transducer is preferred because the pulse signal can be conditioned and converted to a 4-20 mA. (Figure 11)

FIGURE 11


Magnetic Pickup
Support Retainer
Rotor
Support Retainer
S.S. Body
Flow Direction
Rear Rotor Support
Bearing Flush Hole
Thrust Ball
Shaft Bushing
Front Rotor Support

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INFORMATION SHEET

XXVII. Calibrating vortex and ultrasonic flow units

A. Vortex flow units can be calibrated by using a pulse generator to simulate the pulse train from the shedding element.

B. The manufacturer's calibration data is required along with standard electronic instrumentation such as a calibrated signal source, a laboratory grade oscilloscope, and appropriate meters.

C. Using the waveform information from the manufacturer, the pulse signal can be traced, and calibration checked from the source to the pulse, and on to the current circuit where a meter is placed across a dummy load on the 4-20 mA output.

D. Ultrasonic units are calibrated much the same as vortex units in that the source can be simulated by a signal source generator.

E. Following the manufacturer's calibration procedure step by step with standardized instruments will yield waveform, voltage, and current comparisons that will result in proper calibration.

(NOTE: Because of the cost of personnel and training personnel, along with the high cost of standards for recalibration of instruments, much of the calibration of specialized instrumentation is done by calibration service companies.)

XXVIII. Troubleshooting flow instrumentation

A. The bulk of flow instrumentation troubleshooting is still centered around ΔP systems.

B. Checking the output from a ΔP transmitter primary element is done by checking the two pressures from the element for a known flow condition.

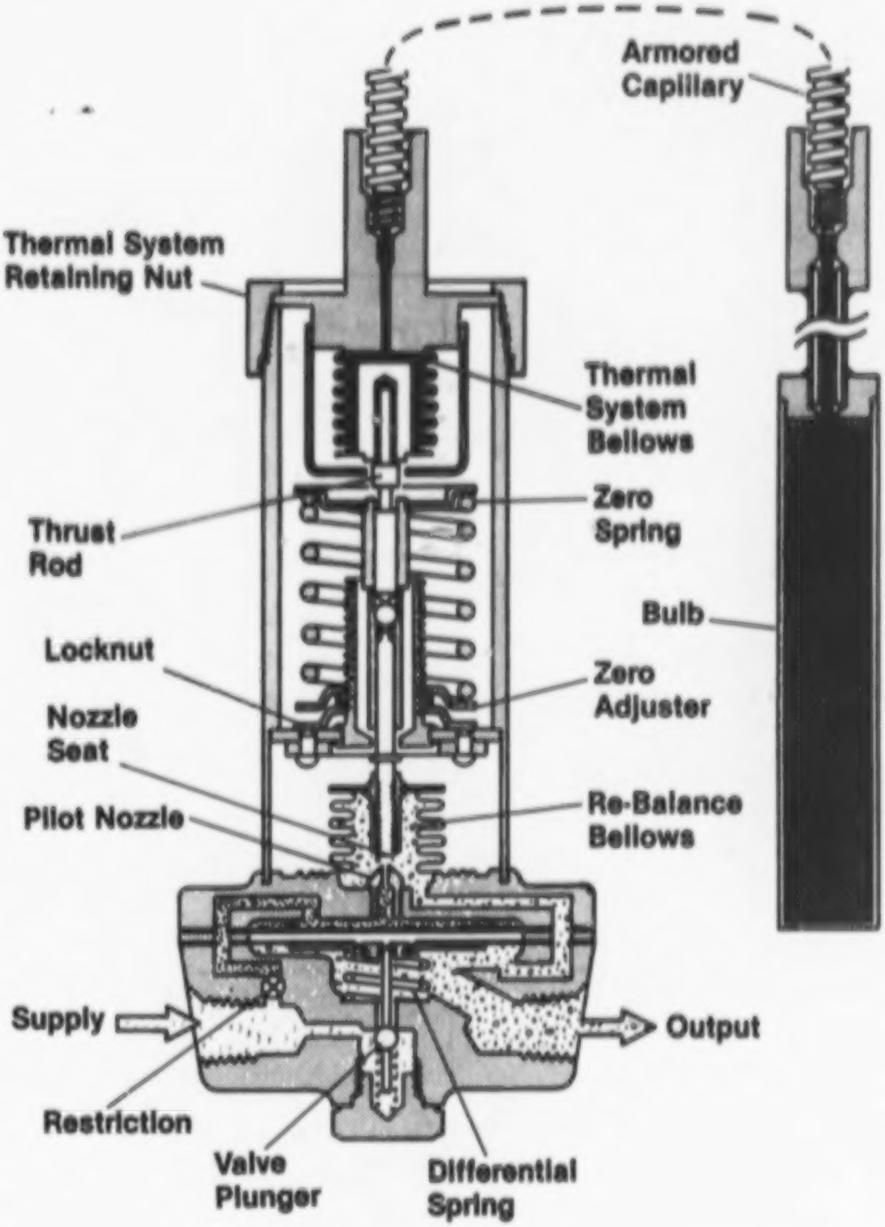
C. When a unit is faulty, it is replaced, and the faulty unit should be sent back to the shop for repair and recalibration.

D. The transmitter can be checked in the field by placing a meter in the 4-20 mA line, and reading current output for known flow conditions.

E. If the transmitter is pneumatic, a gauge should be placed on the 3-15 psi output, and the pressure should be monitored for known flow conditions.

F. Vortex, ultrasonic, and turbine systems can be checked in the field by a qualified instrument technician with appropriate meters and a portable precision oscilloscope, but most work on these units is done on the bench after the faulty unit has been swapped out for a known good unit.

Temperature Transmitter


Armored Capillary
Thermal System Retaining Nut
Thermal System Bellows
Thrust Rod
Zero Spring
Bulb
Locknut
Zero Adjuster
Nozzle Seat
Pilot Nozzle
Re-Balance Bellows
Supply
Output
Restriction
Valve Plunger
Differential Spring

Courtesy Moore Products Co.

TRANSDUCERS AND TRANSMITTERS
UNIT III

JOB SHEET #1 — CALIBRATE AND TEST A DIFFERENTIAL PRESSURE TRANSMITTER

A. Equipment and materials

1. Safety glasses
2. DP transmitter (Taylor 390 series or equivalent)
3. Pneumatic calibrator (Wallace and Tiernan Series 65-120)
4. Tubing and fittings
5. Basic hand tools
6. Pencil

B. Routine #1 — Preparing the transmitter for calibration

1. Put on safety glasses.

   (CAUTION: If you were actually removing a transmitter from service, the following procedures would have to be followed carefully to avoid personal injury and damage to the equipment.)

2. Remove the transmitter from a flow installation with the following procedure:

   a. Equalize pressure in both sides of the measuring element by opening the equalizing valve between the HI and LO sides.

   b. Close shut-off valves between process and HI and LO sides of the measuring element.

   c. Disconnect process connecting lines from the HI and LO sides of the measuring element.

3. Remove the transmitter from a level installation with the following procedure:

   a. Close shut-off valve between tank and LO side of measuring element.

   b. Close shut-off valve between tank and HI side of the measuring element.

   c. Disconnect the process connecting line from the LO side of the measuring element.

   d. Disconnect process connecting line from the HI side of the measuring element.

JOB SHEET #1

4. Take the transmitter to a clean, open area on a test bench.

   ☐ Have your instructor check your work.

C. Routine #2 — Setting up the test apparatus

1. Set the pneumatic calibrator, and the DP transmitter close enough together that they can be conveniently connected.

2. Connect the bench air supply to the air supply connection on the calibrator.

   (NOTE: Follow the illustration in Figure 1 that accompanies this job sheet during your set-up and calibration routines.)

3. Connect an air line from the supply connection (S) on the transmitter to P-1 on the calibrator.

4. Make sure the drain and vent plugs on the HI side of the transmitter are tight.

5. Connect an air line from the HI side connection on the transmitter to P-2 on the calibrator.

   (NOTE: The LO side of the transmitter should be vented (open) to atmosphere.)

6. Connect an air line from the output connection (O) on the transmitter to P-3 on the calibrator.

7. Turn regulators 1 and 2 on the calibrator fully counterclockwise to make sure they are off.

8. Turn on bench air.

9. Leave "S" port open to atmosphere.

10. Turn the selector valve on the calibrator to P-1, and adjust supply pressure to 20 psi, using regulator #1, and reading the pressure on the calibrator gauge.

11. Turn the selector valve to P-3, and read the transmitter output which should be 3 psi.

12. Calculate the calibrator settings for each % of input and enter the figures in the spaces under Pneumatic Calibrator Setting on your Pre-Calibration Data Chart.

    (NOTE: Refer to handout #1 if you have any problem calculating these standard settings.)

13. Turn the calibrator selector valve to P-2, and set the pressure for the standard at 10%.

JOB SHEET #1

14. Turn the selector valve to P-3, read the transmitter output, and record the transmitter output on the pre-calibration data chart.

15. Repeat the previous two steps for each of the percentages of input and output listed on the precalibration data chart.

16. Complete your pre-calibration graph with the information from your pre-calibration data chart.

☐ Have your instructor check your work.

D. Routine #3 — Calibrating the DP transmitter

1. Put on safety glasses.

2. Adjust span screw to desired span setting.

Example: Since this is a zero based calibration, the span, in U.S. units, is 120 inches of water for 0 to 120 inch range.

3. Adjust input to lower range value.

Example: In U.S. units, the low range would be 0 inches of water for a 0 to 120 inch range.

4. Look for a transmitter output of 3 psi, ±0.02:

   a. If the reading is above 3 psi, turn the zero screw counterclockwise to decrease output to proper span.

   b. If the reading is below 3 psi, turn the zero screw clockwise to increase output to proper span.

5. Adjust input to upper range value:

   a. If the reading is above 15 psi, ±0.06, turn the span screw clockwise to decrease output to proper span.

   b. If the reading is below 15 psi, turn the span screw counterclockwise to increase output to proper span.

6. Repeat Step 5 until the transmitter's zero and span are calibrated.

☐ Have your instructor check your calibration.

E. Routine #4 — Post-testing and recalibrating the transmitter

1. Put on safety glasses.

JOB SHEET #1

2. Transfer your pneumatic calibrator settings from your pre-calibration chart to the post-calibration data chart under the column for pneumatic calibrator settings.

3. Turn the selector valve to P-2, and set the pressure for the standard at 10%.

4. Turn the selector valve to P-3, read the transmitter output, and record the transmitter output on the post-calibration data chart.

5. Repeat the previous two steps for each of the percentages of input and output listed on the post-calibration data chart.

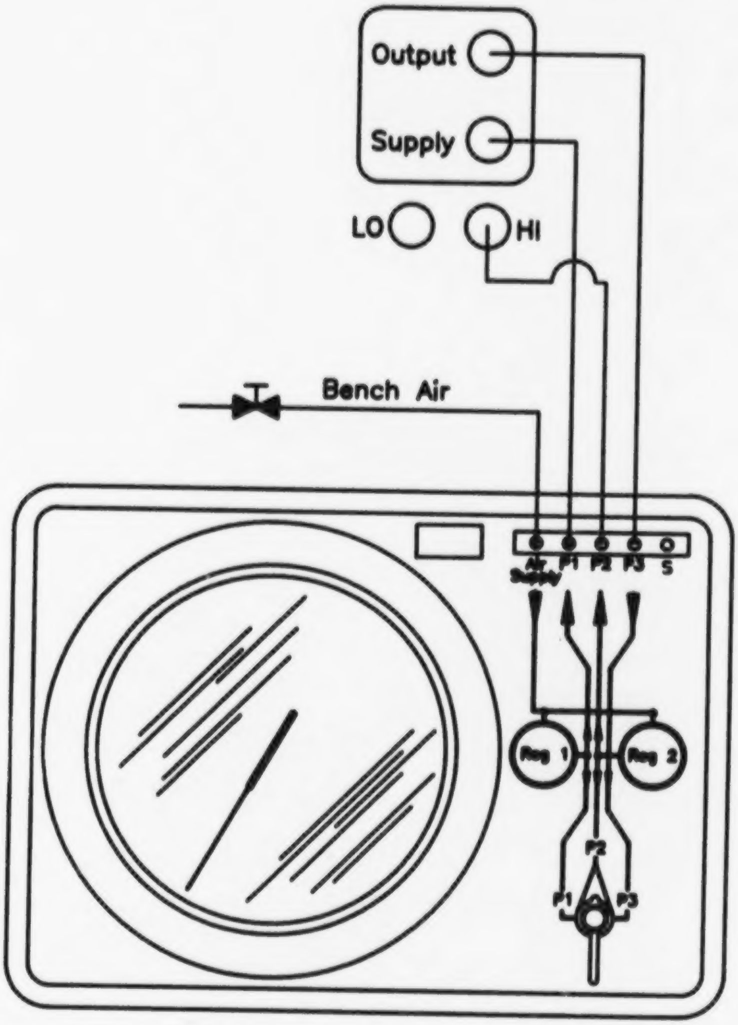
6. Complete your post-calibration graph with the information from your post-calibration data chart.

   ☐ Have your instructor check your work.

7. Clean up area and return equipment and materials to proper storage.

JOB SHEET #1

FIGURE 1


Output
Supply
LO
HI
Bench Air
Air Supply
P1
P2
P3
S
Reg 1
Reg 2
P2
P1
P3

JOB SHEET #1

Calibration Data Sheet

Technician's Name: ______________________ Title: ______________

Standard Used: ______________________________________

Manufacturer: ______________________ Serial #: ______________

Instrument Calibrated: ______________________________________

Manufacturer: ______________________ Serial #: ______________

Date: ______________________ Field ☐ Bench ☐

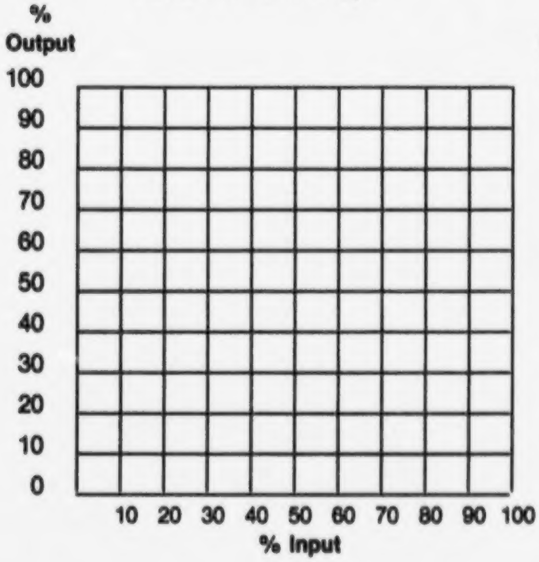
Pre-Calibration Data Chart

% Input	Pneumatic Calibrator Setting in H^2O	Transmitter Output in PSI
90		
70		
50		
30		
10		

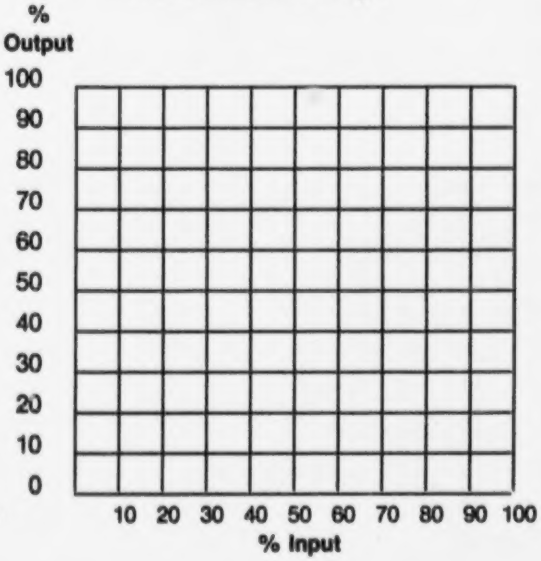
Post-Calibration Data Chart

% Input	Pneumatic Calibrator Setting in H^2O	Transmitter Output in PSI
90		
70		
50		
30		
10		

Pre-Calibration Graph



Post-Calibration Graph



TRANSDUCERS AND TRANSMITTERS
UNIT III

JOB SHEET #2 — PRE-TEST, CALIBRATE, AND POST-TEST A PNEUMATIC PRESSURE TRANSMITTER

A. Equipment and materials

1. Safety glasses
2. Plastic tubing
3. Pneumatic pressure transmitter (Foxboro model 11GM)
4. Pneumatic calibrator (Wallace & Tiernan, series 65-120)
5. Calibration data sheet
6. Hex-key wrench, $^3/_{32}$"
7. Pencil or pen
8. Bench supply air

B. Routine #1 — Setting up the pneumatic calibrator

1. Put on safety glasses.
2. Place the calibrator and the pressure transmitter in convenient work positions on a test bench.
3. Connect bench air line to the air supply connection on the pneumatic calibrator.

   (NOTE: Refer to Figure 1 that accompanies this job sheet during set-up and calibration.)
4. Connect the air line from the supply connection on the transmitter to P-1 on the calibrator.
5. Connect the air line from the input connection on the transmitter to P-2 on the calibrator.
6. Connect the air line from the output connection on the transmitter to P-3 on the calibrator.
7. Turn calibrator regulators 1 and 2 fully counterclockwise to make sure they are off.

   ☐ Have your instructor check your calibrator set-up.

JOB SHEET #2

C. Routine #2 — Pretesting the transmitter

1. Put on safety glasses.

2. Turn on bench air.

3. Turn the selector valve on the calibrator to position P1, and adjust the air supply pressure by turning regulator 1 clockwise as you read the inner psi scale on the calibrator.

4. Turn the selector valve on the calibrator to position P3, and read the output of the transmitter.

5. Record and graph all pre-calibration transmitter readings on the Calibration Data Sheet that accompanies this procedure.

6. Adjust input air pressure by turning the selector valve on the calibrator to position P2, and adjusting regulator 2.

7. Make corresponding transmitter output readings by frequently turning the selector valve to position P3.

8. Complete pre-calibration data and pre-calibration graph on the data sheet that accompanies this job sheet.

☐ Have your instructor check your pre-test.

D. Routine #3 — Making the overrange stop adjustment

1. Put on safety glasses.

(NOTE: The overrange stop prevents damage to both the flapper-nozzle and the dashpot, and the stop should always be checked for correct adjustment before calibration.)

2. Turn on air supply, and apply pressure to the transmitter so that output is stabilized at a value between 3 and 15 psi (20 to 100 kPa).

(CAUTION: Do not move the force bar if the overrange stop is loose or disconnected.)

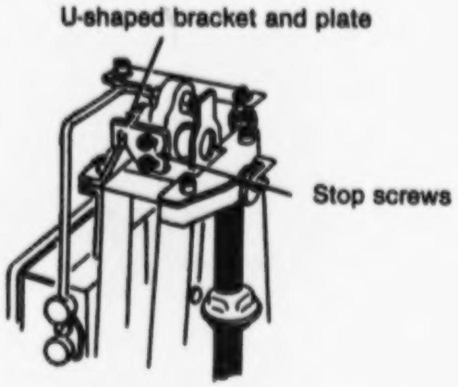
3. Check the clearance between both sides of the overrange stop, the U-shaped bracket, and the plate. (Figure 2)

   a. If you can slide a piece of paper between each side of the stop and the plate, adjustment is okay.

JOB SHEET #2

b. If the paper test fails, loosen the stop screws with a $^3/_{32}$" hex-key wrench, reposition the stop to get correct clearance, and retighten the screws.

FIGURE 2


U-shaped bracket and plate
Stop screws

Courtesy the Foxboro Company

☐ Have your instructor check your work.

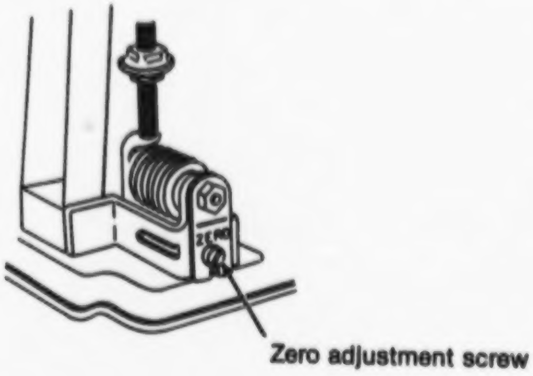
E. Routine #4 — Making zero and span adjustments

1. Put on safety glasses.
2. Adjust calibration supply air so that there is no pressure on the transmitter.

   (NOTE: Remember that you get your transmitter output reading on P-3 of your calibrator.)

3. Adjust the zero adjustment screw so that output on the test gauge reads 3 psi.

   FIGURE 3

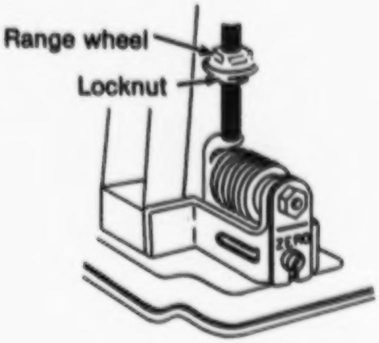

ZERO
Zero adjustment screw

Courtesy the Foxboro Company

JOB SHEET #2

4. Adjust supply air to 15 psi, and check for a 15 psi output from the transmitter.
   a. If output is too low, loosen the locknut on the range wheel, and turn the range wheel down to increase output pressure.

FIGURE 4



Courtesy the Foxboro Company

   b. If output is too high, loosen the locknut on the range wheel, and turn the range wheel up to decrease output pressure.

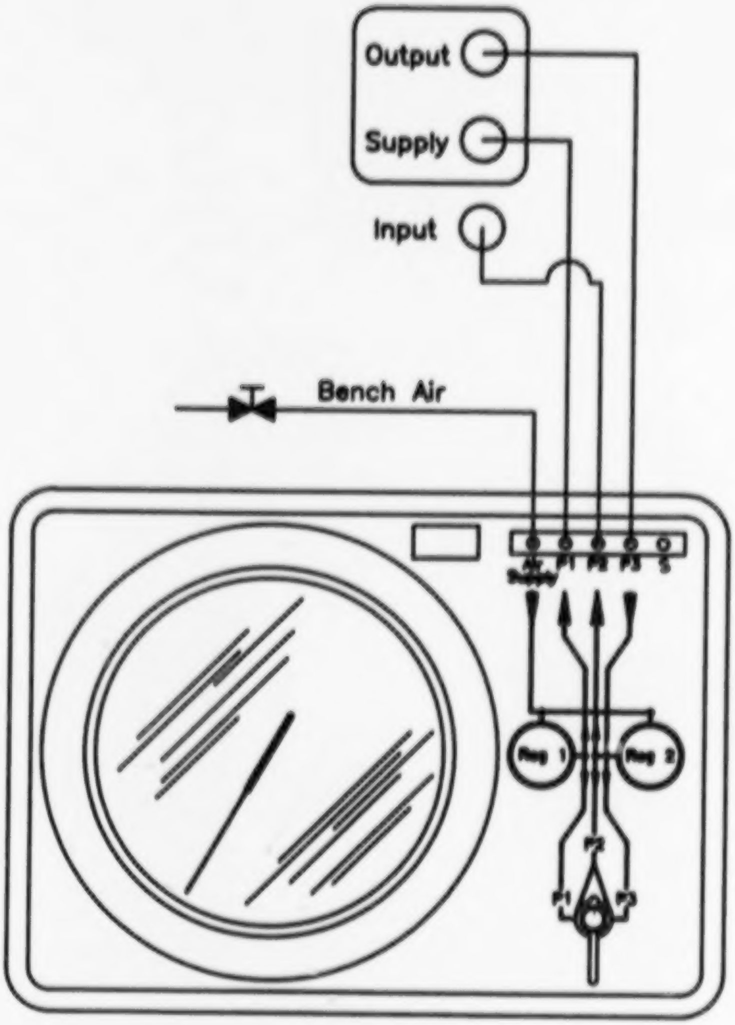
5. Retighten range wheel locknut after adjustment is completed.
6. Complete your post-calibration chart and graph.

   ☐ Have your instructor check your work.

7. Dismantle set-up equipment.
8. Return equipment and materials to proper storage.

JOB SHEET #2

FIGURE 1


Output
Supply
Input
Bench Air
Air Supply
P1
P2
P3
S
Reg 1
Reg 2
P2
P1
P3

JOB SHEET #2

Calibration Data Sheet

Technician's Name: ______________________ Title: ____________

Standard Used: ______________________________

Manufacturer: ______________________ Serial #: ____________

Instrument Calibrated: ______________________________

Manufacturer: ______________________ Serial #: ____________

Date: ______________________ Field ☐ Bench ☐

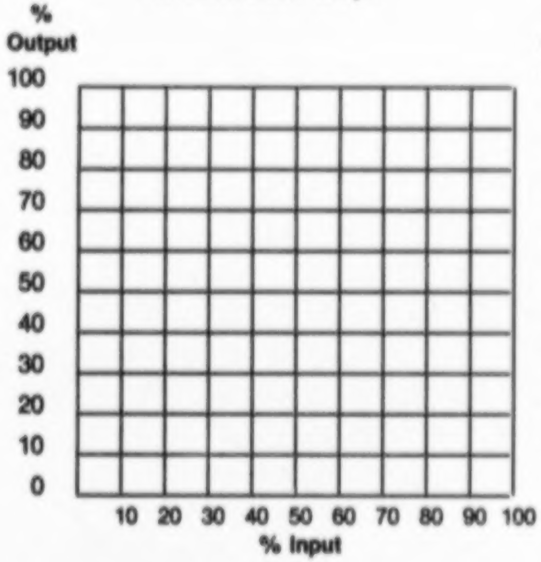
Pre-Calibration Data Chart

% Input	Pneumatic Calibrator Setting in H_2O	Transmitter Output in PSI
90		
70		
50		
30		
10		

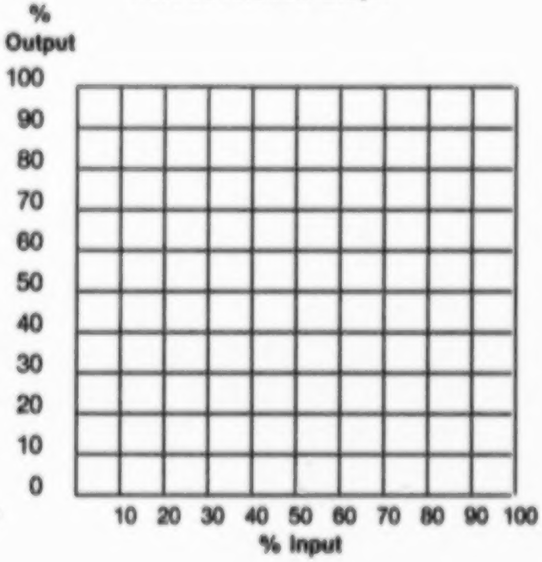
Post-Calibration Data Chart

% Input	Pneumatic Calibrator Setting in H_2O	Transmitter Output in PSI
90		
70		
50		
30		
10		

Pre-Calibration Graph



Post-Calibration Graph



TRANSDUCERS AND TRANSMITTERS
UNIT III

JOB SHEET #3 — FIELD SERVICE A TEMPERATURE TRANSMITTER

A. Equipment and materials

1. Safety glasses
2. Temperature transmitter (Moore model series 33 Nullmatic or equivalent)
3. Basic hand tools
4. Non-abrasive solvent and pan
5. Lint-free shop cloth
6. Pipe cleaner

B. Routine #1 — Cleaning the restriction screw

1. Put on safety glasses.
2. Turn off supply air.
3. Remove the restriction screw.

   (NOTE: Refer to Figure 1 as needed to complete the routines in this job sheet.)

4. Remove the filter screen from the restriction screw, and soak it in solvent as you complete other steps in this routine.
5. Remove the knurled cleaning wire located in the base of the transmitter.
6. Clean the small orifice in the end of the restriction screw with the cleaning wire.
7. Soak the restriction screw in solvent if the orifice is blocked, and then use the cleaning wire to remove the blockage.
8. Check the O-ring on the restriction screw, and replace it if it is cut or gouged.
9. Remove the filter screen from the solvent, and blow air through it to dry it.
10. Place the filter screen back on the restriction screw, replace the screw in the base of the transmitter, and make sure it is tight.
11. Replace the cleaning wire in the base of the transmitter.

    ☐ Have your instructor check your work.

JOB SHEET #3

C. Routine #2 — Cleaning the valve plunger

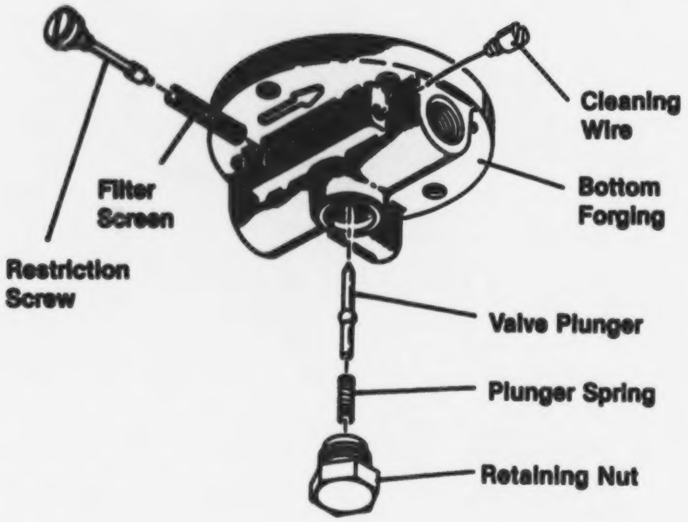
1. Put on safety glasses.
2. Turn off supply air.
3. Remove the retaining nut at the bottom of the transmitter, and hold your hand beneath it as it comes out because the valve plunger and spring will drop out.
4. Reach in with a lint-free shop cloth and clean the supply seat in the transmitter.
5. Use a pipe cleaner to reach in and clean the transmitter exhaust seat.
6. Complete your post-calibration chart and graph.

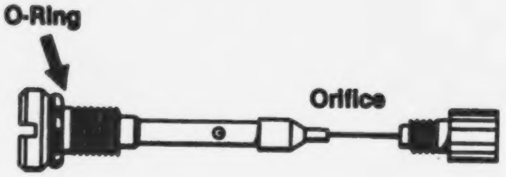
   ☐ Have your instructor check your work.

7. Replace the valve plunger and spring, and make sure the spring is on the bottom end of the plunger.
8. Replace and tighten the retaining nut.
9. Clean area, and return equipment and materials to proper storage.

JOB SHEET #3

FIGURE 1


Cleaning Wire
Bottom Forging
Filter Screen
Restriction Screw
Valve Plunger
Plunger Spring
Retaining Nut


O-Ring
Orifice

Courtesy Moore Products Company

TRANSDUCERS AND TRANSMITTERS
UNIT III

PRACTICAL TEST #1
JOB SHEET #1 — CALIBRATE AND TEST A DIFFERENTIAL PRESSURE TRANSMITTER

Student's name ______________________________ **Date** ____________

Evaluator's name ____________________________ **Attempt no.** _____

Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Prepared transmitter safely for calibration.	1.	☐	☐
2. Set up test apparatus properly.	2.	☐	☐
3. Recorded and graphed pre-calibration readings.	3.	☐	☐
4. Calibrated transmitter properly.	4.	☐	☐
5. Graphed post-test readings properly.	5.	☐	☐
6. Observed personal and equipment safety.	6.	☐	☐
7. Cleaned area and returned equipment to storage.	7.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #1 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:

Equipment and Materials	Properly selected and properly used 4	Properly selected and acceptably used 3	Poorly selected and/or used 2	Improperly selected and/or used 1
Calibration Procedure	Well followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Data Recording	All properly entered 4	Almost all entered 3	Too few entered 2	Too few entered or improperly entered 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ______________________________

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

TRANSDUCERS AND TRANSMITTERS
UNIT III

PRACTICAL TEST #2
JOB SHEET #2 — PRE-TEST, CALIBRATE, AND POST-TEST A PNEUMATIC PRESSURE TRANSMITTER

Student's name ______________________ **Date** __________

Evaluator's name ______________________ **Attempt no.** ______

Student instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Set up pneumatic calibrator properly.	1.	☐	☐
2. Pretested transmitter properly.	2.	☐	☐
3. Made overrange stop adjustment as required.	3.	☐	☐
4. Made zero and span adjustments.	4.	☐	☐
5. Recorded pre-test and post-test information.	5.	☐	☐
6. Observed personal and equipment safety.	6.	☐	☐
7. Cleaned area and returned equipment to storage.	7.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #2 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Equipment and Materials	Properly selected and properly used 4	Properly selected and acceptably used 3	Poorly selected and/or used 2	Improperly selected and/or used 1
Testing Procedure	Well followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Data Recording	All properly entered 4	Almost all entered 3	Too few entered 2	Too few entered or improperly entered 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ______________________________

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

TRANSDUCERS AND TRANSMITTERS
UNIT III

PRACTICAL TEST #3
JOB SHEET #3 — FIELD SERVICE A TEMPERATURE TRANSMITTER

Student's name ____________________ **Date** __________

Evaluator's name ____________________ **Attempt no.** ______

Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Removed restriction screw.	1.	☐	☐
2. Cleaned orifice as required.	2.	☐	☐
3. Cleaned filter screen as required.	3.	☐	☐
4. Replaced cleaning wire.	4.	☐	☐
5. Removed valve plunger.	5.	☐	☐
6. Cleaned transmitter exhaust seat.	6.	☐	☐
7. Cleaned area and returned equipment to storage.	7.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #3 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:

Equipment and Materials	Properly selected and properly used 4	Properly selected and acceptably used 3	Poorly selected and/or used 2	Improperly selected and/or used 1
Restriction Screw Cleaning	Well followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Valve Plunger Cleaning	Well followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ______________________________

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

TRANSDUCERS AND TRANSMITTERS
UNIT III

TEST

NAME ______________________________ SCORE ______________

1. Match the terms on the right with their correct definitions.

______a. A process instrument that accepts sensor output and converts it into a standard electrical or pneumatic process signal which is transmitted to an indicator, recorder, controller, or other device

______b. The most common electrical current signal, 4-20 mA, used to transmit process information

______c. The most common air pressure signal, 3-15 psi and 20-100 kPa, used to transmit process information

______d. A device that detects the presence of, and measures the value of a given physical phenomena used in process control

______e. A sensor device that converts a measured phenomena from one form of energy to another

1. Pneumatic standard signal
2. Sensor
3. Transmitter
4. Electrical standard signal
5. Transducer

2. Select true statements concerning pressure transducers by placing an "X" beside each statement that is true.

(NOTE: For a statement to be true, all parts of the statement must be true.)

______a. Pressure transducers are devices that sense or detect pressure, and determine the amplitude of the force applied.

______b. Pressure transducers also convert detected pressure into another energy form, usually pneumatic or electrical, for transmission to a readout or controller.

______c. There are many ways to sense or detect pressure, but the most common systems employ:

1. Manometers
2. Bourdon tubes
3. Bellows

TEST

4. Quartz crystals

5. Diaphragms

6. Capsules

_____d. The basic manometer is a "U" tube device always filled with Mercury.

3. Arrange in order the steps in the operation of a bourdon tube by placing the correct sequence number in the appropriate blank.

_____a. Tip movement pulls or pushes the link, rotates the pinion shaft, and moves the tip of the gauge or the controller mechanism so that pressure is converted or transduced into mechanical motion.

_____b. The link connects with a gear/arm mechanism that turns a pinion which is part of a bearing-mounted shaft.

_____c. The bearing-mounted shaft runs the gauge pointer or control device.

_____d. Pressure received at the socket is routed to the flattened tube, and causes the "C" shaped tube to attempt to straighten, and this results in movement of the tip away from the center.

_____e. The bourdon tube with its 270 degree "C" element is brazed into a socket that can be attached to a pressure source while the other end of the tube is plugged into a tip that has an attachment hole where a link is fastened.

4. Differentiate between spiral and helical bourdon tubes by placing an "X" beside the definition of a helical bourdon tube.

_____a. This bourdon tube is essentially a number of bourdon tubes connected end to end to multiply tube action and increase mechanical movement.

_____b. This bourdon tube is made of extra thick tubing for high pressure applications.

5. Solve problems concerning how diaphragms, capsules, and bellows work by selecting the correct answer.

a. A diaphragm is a basic pressure measuring device that works with what, positive pressure only or both positive and negative pressures?

Answer: ______________________________

b. If the deflection of a capsule is directly proportional to the number of diaphragms in the capsule, then a capsule with two diaphragms would have a deflection twice as great or three times greater than a single diaphragm?

Answer: ______________________________

TEST

c. In an application where increased mechanical drive is required, what would function best, a larger diaphragm or a bellows?

Answer: ____

6. Select true statements concerning piezoelectric crystals by placing an "X" beside each statement that is true.

_____a. A piezoelectric crystal is a combination sensor/transducer because it senses pressure applied on the crystal, and generates electrical pressure or voltage as an output.

_____b. The crystal is placed in a pressure tight vessel, and pressure is applied to the crystal or to a diaphragm attached to the crystal so that the crystal will be compressed in relation to applied pressure.

_____c. Compression causes a crystal to produce AC voltage at opposite ends of the crystal, and electrical leads attached to each end of the crystal connect to the output conductors.

_____d. When application demands, a diaphragm may be attached to the crystal to protect it from chemical reaction, and the diaphragm can supply mechanical advantage.

_____e. Piezoresistive sensors are devices which produce changes in resistance in response to changes in pressure.

7. Solve problems concerning conversion to usable form by selecting the correct answer.

a. Most pressure sensors produce what kind of output, digital or mechanical?

Answer: ____

b. The most common conversions to usable form are analog to digital and mechanical to hydraulic, or mechanical to pneumatic and mechanical to electrical?

Answer: ____

8. Complete statements concerning linear variable resistors and potentiometers by circling the material that best completes each statement.

a. Linear variable resistors convert mechanical output into (**voltage or current, current only**) output.

b. The mechanical output is connected to the movable contact on an LVR, and the mechanical movement changes (**the position of the movable contact, the bias of the LVR**).

TEST

c. Change of the movable contact causes a (**voltage, resistance**) change in proportion to the pressure of the mechanical output.

d. An LVR device can be connected as a potentiometer to vary (**current, voltage**) output, or as a rheostat to vary (**current, voltage**) output.

9. Select true statements concerning linear variable differential transformers by placing an "X" beside each statement that is true.

(NOTE: For a statement to be true, all parts of the statement must be true.)

______a. An LVDT is a three-winding transformer with two identical output windings cross-connected, and wound on each side of a primary input winding.

______b. The primary and secondary coils are wound around a movable core whose movement determines output.

1) When the movable core is centered, the two secondary output coils produce identical voltage output, and since the secondary coils are cross-connected, the voltages cancel each other.

2) When the core moves in one direction or the other, one secondary loses output voltage, and the other secondary produces an AC output voltage in proportion to the change.

3) When the core moves in the opposite direction, there is no voltage produced.

______c. Since the phase is opposite for each output coil, the LVDT will produce an AC output that has amplitude and phase that are proportional to the movement of the core.

______d. When the core is connected to the mechanical output of the pressure device, the signal from the LVDT can produce an output that yields both direction and distance information in the form of phase and amplitude.

10. Select true statements concerning variable capacitance/variable frequency systems by placing an "X" beside each statement that is true.

______a. Since many control devices are digital, they can utilize frequency information directly without analog to digital conversion.

______b. When converting mechanical movement to frequency changes, the mechanical output is connected to a variable capacitor which produces capacitance change in proportion to the mechanical movement produced by pressure output.

______c. The capacitor is connected in a variable oscillator circuit as the frequency determining part of the system, so that when the capacitance changes due to mechanical/pressure changes, it causes the AC output frequency to change in proportion to the pressure.

______d. Since the oscillator frequency is not usually high, the AC output can be transmitted only a short distance.

TEST

11. Select true statements concerning mechanical-to-pneumatic pressure converters by placing an "X" beside each statement that is true.

_____a. Converting mechanical output into pneumatic pressure for transmission is often accomplished with a mechanical flapper that moves in front of a nozzle that has air blowing from it.

_____b. In a pneumatic pressure converter, supply air flows through a fixed restriction to a nozzle so that if the flapper moves toward the nozzle, air flow is cut off or reduced, and air pressure across the restriction is lowered.

_____c. The system produces a variable air pressure output which is proportional to the mechanical input.

12. Solve problems concerning indicators by selecting the correct answer.

a. Indicators are used to monitor what, single parameters in a system, multiple parameters in a system, or both?

Answer: ______________________________

b. Indicators are almost always what, digital or pneumatic, electrical, or digital depending on system requirements?

Answer: ______________________________

13. Complete statements concerning pressure transmitters by circling the material that best completes each statement.

a. Pressure transmitters receive input from a pressure source, and convert the signal to **(a form compatible with other system devices, an analog signal)**.

b. A pneumatic pressure transmitter monitors pressure input and converts it to the **(3-15 psi, 0-12 psi)** output or other pneumatic standard.

c. An electric pressure transmitter monitors pressure input and converts it to a **(4-10 mA, 4-20 mA)** output or other electrical or digital standard.

14. Solve problems concerning differential pressure transmitters by selecting the dorrect answer.

a. A ΔP transmitter receives input from two pressure sources and gives an output equal to what, the sum of the two inputs or the difference of the two inputs?

Answer: ______________________________

b. ΔP transmitters are typically used with orifice plates, but can they function with venturi tubes or pitot tubes, yes or no?

Answer: ______________________________

TEST

15. Complete statements concerning calibrating ΔP transmitters by circling the material that best completes each statement.

    a. Because ΔP transmitters monitor critical parameters in a system, they should be calibrated at (**regularly scheduled, monthly**) intervals.

    b. Calibration data should always be completed, and a correctly plotted calibration curve (**may also be, is**) required.

16. Solve problems concerning level transmitters by selecting the correct answer.

    a. Level transmitters have two distinct parts which are what, a receiver and a relay or a sensor element and a transducer/transmitter?

    Answer: ______________________________

    b. Level sensors are classed according to what, their size or their method of sensing liquid level?

    Answer: ______________________________

17. Match types of level sensors with their characteristics.

_____a. 1) Hollow metal or plastic objects that ride on the level interface.

2) Attached to a measuring device by a cable or tape, and may ride up and down in a stilling well.

_____b. 1) Hollow metal objects that output mechanical force because they displace liquid rather than ride on the liquid interface.

2) They are coupled to a measuring system via a shaft or tube, and are normally sealed from the liquid being measured by a packless metal seal.

_____c. 1) In principle, these probes are two plates of a capacitor, and the liquid is the dielectric material between the plates that causes the devices to produce capacitance.

1. Conductance probes
2. Displacers
3. Static head sensors
4. Floats
5. Capacitance probes

TEST

2) The capacitor is connected into an oscillator circuit whose output frequency changes with a change in liquid level.

3) The devices interface well with electrical output transmitters because the action of the probes is an electrical parameter.

_____d. 1) Simple devices that depend on the measured liquid being an electrical conductor.

2) Electrical probes are placed in a vessel at points where level measurement is desired.

3) When liquid reaches the probes, current flows, and the present level is logged by the system.

4) Knowing where level is at any place in a vessel requires installation of probes at each level increment.

_____e. 1) Static head is the pressure exerted by the height of a liquid in a vessel as measured by a pressure sensor at the bottom of the vessel.

2) In this instance, static head means that the vessel is open to atmosphere.

3) With a closed vessel, the pressures at the top and bottom must be compared by a measuring device.

18. Solve problems concerning calibrating level transmitters by selecting the correct answer.

a. Calibrating a level transmitter should begin with what, a good set of tools or a provision for simulating sensor output to the transmitter?

Answer: ____

TEST

b. Manufacturers calibration procedures should be followed how, to the letter or as closely as is convenient?

Answer: ____________________

c. Calibrating a level transmitter with an uncalibrated test instrument is what, a learning experience or a waste of time?

Answer: ____________________

19. Select true statements concerning troubleshooting level transmitters by placing an "X" beside each statement that is true.

_____a. Always check the manufacturer's literature for specific problems, but use systematic troubleshooting procedures as required.

_____b. Make sure the instrument is properly installed because position, orientation, and placement are critical to level transmitters.

_____c. Verify that the instrument is appropriate for the type and range specified for the installation.

_____d. When you don't know what the problem is, run the calibration tests, and the trouble will probably occur during the tests.

_____e. Visual checks will show damaged or burned parts of electrical instruments, and mechanical damage on any system can usually be spotted with a visual check.

_____f. Substituting a good unit for a suspected faulty one is not recommended.

_____g. If none of the tests isolate the problem, review the system to see what other part of the equipment may be causing the part in question to fail.

_____h. In electrical systems, the root problem may be several stages away from the apparent problem.

_____i. In troubleshooting it is very important to understand the entire system, and that includes mechanical, pneumatic, and electrical/electronic subsystems.

20. Match temperature sensors with their characteristics.

_____a. 1) These sensing devices cover temperature ranges commonly used in process applications, and have a wide range of applications because they are simple, rugged, and low cost.

2) These devices need no power supply because they generate a mV signal.

1. Thermistors
2. Filled-thermal systems
3. Thermocouples
4. RTDs

TEST

_____b. 1) These devices are very linear and sensitive, and are usually made from fine wire and connected into a wheatstone bridge circuit in a fashion that produces accuracy as well as linearity.

2) These devices are not generators and do require external circuitry and power supplies.

_____c. 1) These devices are thermal resistors made of metal oxides and semiconductor materials to operate as negative temperature coefficient devices.

2) These devices are low cost, and can be manufactured in almost any shape.

3) These devices are not linear, and do require external circuitry for power, measuring, and linearization.

_____d. 1) These are material expansion devices that can be operated with liquid, vapor, or gas principles.

2) Most configurations have a bulb, a capillary, and a bourdon tube or bellows actuator, and each configuration has distinct ranges, advantages, and limitations.

3) With temperature change, the liquid, gas, or vapor expands or contracts to create a pressure that is transmitted through the capillary to the actuator which produces mechanical motion to drive the transmitter.

21. Select true statements concerning types of temperature transmitters by placing an "X" beside each statement that is true.

_____a. In general, thermocouples, RTDs, and thermistors are used with pneumatic transmitters, and filled-thermal systems are used with electrical transmitters.

_____b. Electrical transmitters used with thermocouples receive the millivolt signals produced by the sensor, and convert it into a 4-20 mA signal.

TEST

_____c. Pneumatic transmitters accept the output from a filled-thermal device or other mechanical device and convert the mechanical motion into a 4-20 psi or 20-100 kPa signal.

_____d. Pneumatic systems are usually force balance systems where the initial pressure change acts on a bellows or diaphragm, and moves a mechanical lever that changes the relationship between a flapper/nozzle or similar device.

_____e. The change in relationship causes a change in pressure drop across a restrictor which moves an air amplifier to produce the 3-15 psi signal.

_____f. The signal is then sent back to the original level by way of a pneumatic bellows which restores the balance in the system.

22. Solve problems concerning calibrating temperature transmitters by selecting the correct answer.

a. To reproduce a temperature sensor output to a transmitter can be done with what, a decade resistance box or a precision power supply?

Answer: ____________________

b. Because temperature changes occur slowly, sensors changed from one bath to another require that the technician do what, wait until the temperature has stabilized or wait exactly three minutes?

Answer: ____________________

23. Select true statements concerning flow sensors/transmitters by placing an "X" beside each statement that is true.

_____a. Most flow measurements are made by using differential pressure across a restriction in a pipe where material flow is monitored.

_____b. Devices such as orifice plates, flow nozzles, and venturi tubes are by far the most common flow measuring systems used by industry.

_____c. In common flow measuring systems, the ΔP transmitter is normally used to measure differential pressure, and should be calibrated on a regular schedule.

_____d. Newer electronics-based equipment uses systems such as vortex shedding flowmeters, ultrasonic flowmeters, transit time systems, and turbine flowmeters.

TEST

24. Complete statements concerning vortex shedding flowmeters by circling the materials that best completes each statement.

    a. Vortex shedding flowmeters are so named because in a section of pipe they have a shedding element that disturbs the flow, and creates circular currents called vortices which are shed **(in the proximity of, upstream from)** the element.

    b. The **(frequency, force)** of the vortex shedding is directly proportional to flow.

    c. A **(sensor, shedding element)** detects vortex shedding and generates an electrical impulse which goes on to a signal amplifier/conditioning transmitter.

    d. The output from the **(sensor, conditioning transmitter)** is equal to flow.

25. Select true statements concerning ultrasonic and Doppler flowmeters by placing an "X" beside each statement that is true.

    _____a. Doppler systems and transit time systems both have high frequency sound transmitters and receivers that are housed separate, except some Doppler systems house the devices in the same case.

    _____b. The transit time system is the more complex of the two systems, and its transmitter is a man-made crystal driven by an electronic oscillator which is also synchronized with the detection circuitry.

    _____c. The transit time system receiver is also a crystal detector which feeds the incoming frequency to the detection-and-comparison circuitry where the comparison will yield the difference in time, and the time difference is converted to flow rate.

    _____d. In ultrasonic flowmeter systems, the velocity of the sound waves will increase in the direction of flow, and decrease in the opposite direction, and the changes in flow rate and sound velocity are proportional.

    _____e. Ultrasound flow measurement is always dependent upon the fluid containing some entrained material in the flow, such as a fluid with bubbles in it.

    _____f. Doppler systems have equipment similar to transit time systems, oscillators to drive the transmitter, crystal transducers, an ultrasonic receiver, phase comparison circuitry, and control circuitry.

    _____g. In the doppler system, the ultrasonic signal is transmitted into the pipe of flowing liquid where the signal frequency and phase are shifted in proportion to the velocity of the flowing fluid.

    _____h. The material suspended in the flow reflects and returns the signal to the receiver where a detector transduces the signal back to an AC electrical signal.

    _____i. The AC signal is then compared with the original signal to produce a signal that can be converted to flow rate.

TEST

26. Select true statements concerning turbine flowmeters by placing an "X" beside each statement that is true.

_____a. Turbine flowmeters are strictly mechanical flow metering systems, and the turbine itself is a rotary blade instrument that fits into the pipe and turns at a speed dependent on the flow rate of fluid through the blades.

_____b. The rate of rotation can only be transferred by gear and cable or shaft to the outside of the pipe.

_____c. The frequency of rotation can be used to produce flow rate on an indicator, or it can be transmitted to another location.

_____d. When the frequency of rotation is to be transmitted, the pulse pick-up coil-type transducer is preferred because the pulse signal can be conditioned and converted to a 4-20 mA signal.

27. Solve problems concerning calibrating vortex and ultrasonic flow units by selecting the correct answer.

a. When calibrating vortex or ultrasonic flow units, it is best to what, trust the advice of a technician who has done it before or follow the manufacturer's calibration procedure step by step?

Answer: ____________________

b. When comparing the calibration of vortex and ultrasonic units, they are what, much the same or as far apart as night and day?

Answer: ____________________

28. Solve problems concerning troubleshooting flow instrumentation by selecting the correct answer.

a. The bulk of flow instrumentation troubleshooting is still centered around what kind of systems, ultrasonic or ΔP?

Answer: ____________________

b. Vortex, ultrasonic, and turbine systems are usually repaired or calibrated on a bench after what, the process has been shut down or the faulty unit has been swapped out for a known good unit?

Answer: ____________________

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

29. Demonstrate the ability to:

a. Calibrate and test a differential pressure transmitter. (Job Sheet #1)

b. Pre-test, calibrate, and post-test a pneumatic pressure transmitter. (Job Sheet #2)

c. Field service a temperature transmitter. (Job Sheet #3)

TRANSDUCERS AND TRANSMITTERS
UNIT III

ANSWERS TO TEST

1. a. 3
   b. 4
   c. 1
   d. 2
   e. 5

2. a, b

3. a. 5
   b. 2
   c. 3
   d. 4
   e. 1

4. b

5. a. Both positive and negative pressures
   b. Twice as great
   c. A bellows

6. a, b, d, e

7. a. Mechanical
   b. Mechanical to pneumatic and mechanical to electrical

8. a. Voltage or current
   b. The position of the movable contact
   c. Resistance
   d. Voltage, current

9. a, c, d

10. a, b, c

11. a, b, c

ANSWERS TO TEST

12. a. Both
    b. Pneumatic, electrical, or digital depending on system requirements

13. a. A form compatible with other system devices
    b. 3-15 psi
    c. 4-20 mA

14. a. The difference of the two inputs
    b. Yes

15. a. Regularly scheduled
    b. May also be

16. a. A sensor element and a transducer/transmitter
    b. Their method of sensing liquid level

17. a. 4
    b. 2
    c. 5
    d. 1
    e. 3

18. a. A provision for simulating sensor output to the transmitter
    b. To the letter
    c. A waste of time

19. a, b, c, d, e, g, h, i

20. a. 3
    b. 4
    c. 1
    d. 2

21. b, d, e, f

22. a. A precision power supply
    b. Wait until the temperature has stabilized

ANSWERS TO TEST

23. a, b, c, d

24. a. In the proximity of
    b. Frequency
    c. Sensor
    d. Conditioning transmitter

25. a, c, d, e, f, g, h, i

26. c, d

27. a. Follow the manufacturer's calibration procedure step by step
    b. Much the same

28. a. ΔP
    b. The faulty unit has been swapped out for a known good unit

29. a. Evaluated according to criteria in Practical Test #1
    b. Evaluated according to criteria in Practical Test #2
    c. Evaluated according to criteria in Practical Test #3

MOORE
√XTRACTOR

SIGNAL CONDITIONING
UNIT IV

UNIT OBJECTIVE

After completion of this unit, the student should be able to list the objectives of signal conditioning, and discuss practical applications of relays, ratio conditioners, and other devices in signal conditioning subsystems. The student should also be able to relate A/D and D/A signal conditioners to their functions, and current-to-pressure and voltage-to-current signal conditioners to their functions. The student should also be able to troubleshoot and calibrate a signal conditioners. These competencies will be evidenced by properly completing the procedures outlined in the job sheets, and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to signal conditioning with their correct definitions.
2. Select true statements concerning the objectives of signal conditioning.
3. Complete statements concerning pneumatic relays.
4. Solve problems concerning electrical ratio conditioners.
5. Solve problems concerning A/D signal conditioning.
6. Solve problems concerning D/A signal conditioning.
7. Solve problems concerning current-to-pressure signal conditioning.
8. Select true statements concerning voltage-to-current signal conditioning.
9. Solve problems concerning calibrating signal conditioners.
10. Select true statements concerning maintenance of signal conditioners.
11. Solve problems concerning troubleshooting signal conditioners.

OBJECTIVE SHEET

12. Demonstrate the ability to:

    a. Calibrate a pneumatic square root extractor. (Job Sheet #1)

    b. Calibrate a multi-function computing relay. (Job Sheet #2)

    c. Calibrate a current-to-pressure transducer. (Job Sheet #3)

SIGNAL CONDITIONING
UNIT IV

SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information sheet.

C. Make transparencies.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Demonstrate and discuss the procedures outlined in the job sheet.

G. In the event a pneumatic calibrator is not available for the job sheets in this unit, pneumatic pressure regulators and high-accuracy test gauges may be substituted. However, any modifications in equipment or procedure should be checked prior to student performance to assure that the apparatus is safe and that the modification will retain the accuracy required for the objective.

H. Have signal conditioning devices available for the students to examine.

I. Use a P&ID or other graphic source to demonstrate the importance of signal conditioning in process control.

J. Invite a local or area technician to talk to the class about troubleshooting and calibrating signal conditioners.

K. Give test.

RESOURCES USED IN DEVELOPING THIS UNIT

A. *Portable Pneumatic Calibrator Series 65-120*. Belleville, NJ 07109: Wallace & Tiernan Division, Pennwalt Corporation, 1983.

B. *Instrumentation Maintenance, Module 3, Pneumatic Transducers, Computing Relays*. Research Triangle Park, NJ 27709: Instrument Society of America, 1981.

C. *Service Instructions, Nullmatic® M/F Relays Model Series 68*. Spring House, PA 19447: Moore Products Co., 1981.

D. *Service Instructions Model 65 Square Root Extractor*. Spring House, PA: Moore Products Co., 1979.

E. *Instructions, Taylor D-C Current-to-Pressure Transducer 1400T, 1401T, Model A*. Rochester, NY 14692: Taylor Instrument, a Division of Combustion Engineering, Inc., 1984.

SIGNAL CONDITIONING
UNIT IV

INFORMATION SHEET

I. **Terms and definitions**

A. Module — A compact housing for an electronic device, including its interface connections for other components in a system

B. OP AMP (operational amplifier) — A high-gain, linear IC that receives two (AC or DC) input signals and amplifies the difference between the two signals to accomplish mathematical functions such as subtracting and inverting

C. Quantizing — Changing an analog voltage to a binary level

D. Recovery system — An output module or subsystem that receives binary output from a computer and changes it to an analog signal

E. Solid state — A general reference to a category of electronic devices ranging from simple diodes to sophisticated ICs whose circuitry is embedded in silicone or other crystalline material for the purpose of controlling electron flow

II. **Objectives of signal conditioning**

A. The preparation of a signal for use in a controller or other process equipment is known as signal conditioning.

B. Signal conditioning has always been an important part of process systems, but has become even more important as systems move into controls that are based on integrated circuits, or systems that are computer based.

C. Signal conditioning can range from a level change in the transfer of energy from a sensor to a transmitter on to the analog to digital conversion that prepares an analog signal for computer control.

D. Signal conditioning is an important part of both pneumatic and electrical systems, but pneumatic signal conditioning is mostly done by boosters and filters that keep signals at appropriate levels, or keep control air clean.

E. Electrical systems present diverse problems in electronic control signal conditioning, and because of the trend toward computerized controls, these devices and subsystems merit special attention.

F. The types of circuits used to condition analog electronic signals have their counterparts in some pneumatic devices, but there is no pneumatic counterpart for digital electronics because what can be accomplished with air circuits would be impractical in terms of cost, size, and response time.

INFORMATION SHEET

III. **Pneumatic relays**

A. Pneumatic relays modify pneumatic signals, but they do not change pneumatic signals to other forms.

(NOTE: Transducers do change one energy form to another, but pneumatic relays only modify a pneumatic signal.)

B. A volume booster increases air volume without increasing air pressure, and is often used where increased air volume is needed to operate a final element.

C. Pneumatic computing relays perform complex calculations such as adding, subtracting, averaging, or multiplying signals.

D. Computing relays usually work with more than one input to compute a new value; a square root extractor is a good example of a computing relay.

E. Amplifying relays change a signal level in accordance with a fixed ratio such as 2 to 1 or 3 to 1, and these relays are also called ratio relays.

F. A reversing relay reverses an input signal to its opposite value such as receiving a 3 psi input and reversing it to 15 psi.

G. A reducing relay usually reduces an input signal on a fixed ratio of 1 to 2 or 1 to 3.

EXAMPLE: With a 1 to 2 ratio, a 4 psi input would be reduced to 2 psi.

IV. **Electrical ratio conditioners**

A. Electrical ratio conditioners are amplifiers or attenuators that change a signal level in accordance with some fixed ratio.

B. AC signals use special low-loss transformers to change the ratio up or down in voltage or current.

C. DC signals use precision amplifiers to ratio the signal up, and precision attenuators to ratio the signal down.

D. Modern circuits use operational amplifiers or OP-AMPS to accomplish both AC and DC ratios.

E. Another type of ratio subsystem is the product ratio conditioner that receives two inputs, and produces a signal which is transmitted to a digital computer controller where the ratio information is extracted and used to make a control decision.

INFORMATION SHEET

V. A/D (analog to digital) signal conditioning

A. As more and more control systems become computerized, A/D and D/A signal conditioners are becoming more common.

B. The A/D systems are especially important because most sensors and transducers produce analog or continuous signal outputs, but a computer cannot deal with any signal that is not binary.

C. Part of the A/D subsystem is the analog multiplexer which receives a number of analog signal and switches these incoming signals into the sampling system of a converter.

D. Multiple signals are accessed because a computer is very fast, analog signals are very slow, and the converter is used because it can handle many signals.

E. From the multiplexer, the sampling circuit receives the analog signals in a time sequence, takes a small slice of each signal at a very high rate of speed, and sends the sample to the quantizer or digitizer circuit where it is converted to binary.

(NOTE: It is important that the samples be sent in order because they are samples of waveforms, and must be kept in order.)

F. The quantizer or digitizer accepts the sample, and produces a quantum level signal which is a discrete step in the binary order, and can give the computer binary information that it can use.

G. The sampler and quantizer must be designed to work at the same rate so that the small sample window agrees with the timing of the binary quantum steps, because if they do not agree, the error produced can be disastrous.

H. Filters are used between sampler and quantizer circuits to minimize multiple spectrum signals that can be produced by the sampler.

VI. D/A (digital analog) signal conditioning

A. When a computer has finished with the signals from an A/D subsystem, it must convert the signal back to analog to send the results to the final element, and run the linear devices that are used to change the process.

B. The D/A subsystem is much simpler than the A/D subsystem, and many of the standard A/D systems have a built-in D/A subsystem as part of the operation circuitry.

C. The simplest D/A subsystems have a resistance network connected to the parallel lines of the computer output, and each binary output is 'weighted,' and the combination is summed to make an accurate analog image of each binary number coming out of the computer.

INFORMATION SHEET

EXAMPLE: If a computer port has four output lines, the highest line would have a weight value of 8, the next line 4, the next line 2, and the lowest line 1. If the highest and lowest lines were binary one, then the combination of the 8 and 1 weights would, at the summing output, give an analog weight of 9.

D. Many D/A circuit outputs also have a demultiplexer to switch the appropriate output signal to its proper analog output line, and the system may also have a "sample-and-hold circuit" that helps reconstruct the sampled signal so that it is held at the appropriate analog value between signals.

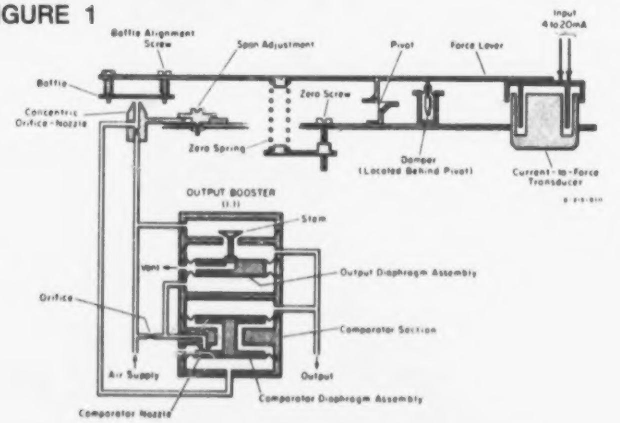
VII. **Current-to-pressure signal conditioning** (Figure 1)

A. Most I/P (current to pressure) systems are used to interface electrical controller signals with the pneumatic signal used to run the air motor that drives a control valve.

B. Also called converters, the I/P systems work as follows:

1. Current flowing from the control system in 4-20 mA signals is connected to a coil in the I/P converter where the current flow pulls an armature attached to the core of a magnet
2. The change in armature position is connected to the flapper of a flapper/nozzle system that changes air flow from the nozzle
3. The change in air flow from the nozzle causes a change in pressure across the orifice, and this change connects to an air relay which produces 3-15 psi in proportion to the 4-20 mA input current

FIGURE 1


Input
4 to 20mA
Baffle Alignment Screw
Span Adjustment
Pivot
Force Lever
Baffle
Zero Screw
Concentric Orifice-Nozzle
Zero Spring
Damper (Located Behind Pivot)
Current-to-Force Transducer
OUTPUT BOOSTER (1:1)
Stem
Vent
Output Diaphragm Assembly
Orifice
Comparator Section
Air Supply
Output
Comparator Diaphragm Assembly
Comparator Nozzle

Courtesy Bailey Controls Company

INFORMATION SHEET

VIII. Voltage-to-current signal conditioning

A. Since the output of many transducers is an electrical voltage instead of current, a voltage-to-current converter is used to convert voltage into the 4-20 mA standard signal.

B. In older systems, the task of voltage to current conversion was reasonably complex because the DC input signal was chopped to form an AC signal which was fed into a voltage-to-current transformer, and this current signal was rectified back to DC to produce the 4-20 mA standard signal.

C. In modern systems the voltage-to-current conversion is accomplished by one integrated circuit which is an OP-AMP (operational amplifier).

D. The OP-AMP circuit is characterized by high input impedance, and very low output impedance, making it a natural voltage-to-current converter.

E. The OP-AMP gain can be set externally by a pair of resistors, and this makes it easy to set the proportion of voltage input to produce the 4-20 mA standard output signal.

IX. Calibrating signal conditioners

A. Calibrating each signal conditioning device means following manufacturer's specifications, but in general, the input signal is supplied by a test bench input or generator, and the output is measured with a meter or oscilloscope to verify the proper input/output signal relationships.

B. D/A and A/D systems are normally modular or IC packages, and standard procedures can be used for calibration, but if the systems aren't modular, the circuit boards containing the systems can be tested with appropriate signal generators and oscilloscopes.

C. Current-to-pressure converters can be calibrated by applying the live zero of the 4-20 mA signal, and adjusting the mechanical adjusting screw to make the air output 3 psi.

D. Complete the I/P calibration by applying full scale current, and adjusting the 15 psi output to give full range of control.

X. Maintenance of signal conditioners

A. Although the I/P converter must be periodically cleaned and adjusted, most signal conditioners are modular, must be checked for proper operation according to an appropriate schedule, and replaced if they develop a problem.

B. What few mechanical relays that are left can be maintained by cleaning the contacts, and readjusting the tension on the relay.

INFORMATION SHEET

C. Points on mechanical relays should be dressed with a point file, a tension gauge should be applied to the relay armature, and a bending tool should be used to bend the spring enough to set proper tension.

XI. **Troubleshooting signal conditioners**

A. Some signal conditioning systems may require periodic replacement, but routine troubleshooting usually consists of measuring the signal in and out of a module.

B. In the case of digital converters, an oscilloscope must be used to view the signal sampling and quantization by the A/D, and the recovery by the D/A module.

C. The A/D and D/A can be treated as a single module because the analog input signal can be measured, and the analog output signal can be compared to the input signal for correct action, but this can be a tricky task because the troubleshooter must remember that the digital computer or digital controller is between the A/D and D/A module.

SIGNAL CONDITIONING
UNIT IV

HANDOUT #1 — TROUBLESHOOTING SQUARE ROOT EXTRACTORS

Background

Technicians are routinely required to troubleshoot flow loops where square root extractors are used to linearize the flow signal from a differential pressure transmitter. Square root extractors are sometimes single components in a flow loop, but they can also be incorporated into controllers, smart transmitters, and distributed control systems. To effectively troubleshoot a square root extractor, a technician must be able to relate non-linear and linear signals to the actual flow in the loop. For example, an indicator on a differential transmitter may be indicating 25% while the controller indicates 50% flow. By comparing the non-linear/linear signals, a technician could quickly determine that both signals are compatible with the 50% flow in the loop. Let's put it in graphic form so it will be easier to demonstrate.

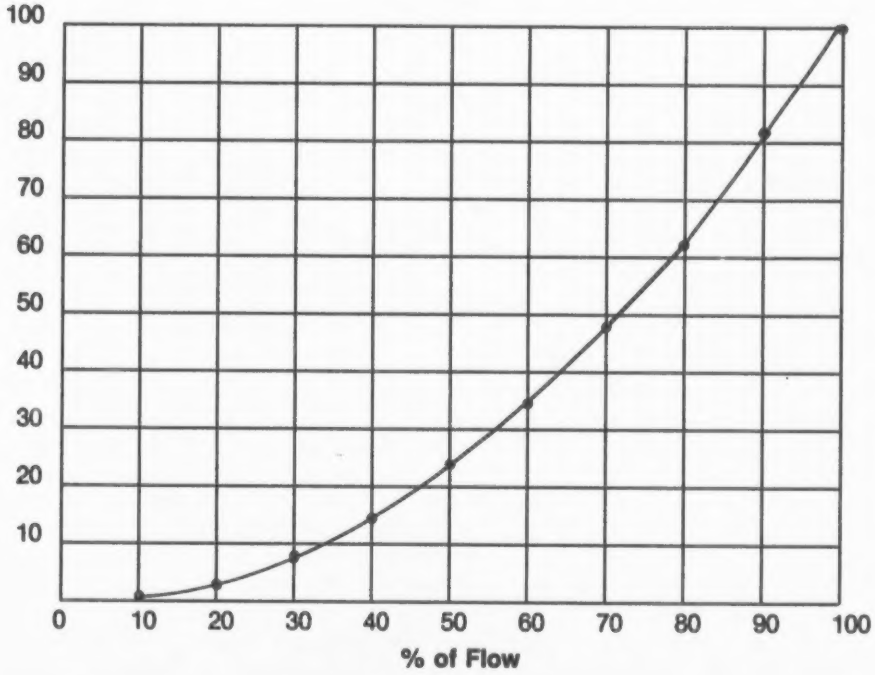
The differential pressure/flow relationship

To quickly construct a ΔP/Flow Chart, begin with a 0-100% vertical scale on the left of the chart to show percent of span, and a 0-100% horizontal scale at the bottom of the chart to show percent of flow. Starting at the top left 100% span, imagine inserting a decimal so that the figure becomes 10. Multiply 10 × 10 to get the square of 10 which is 100 and place a prominent dot at the point where 100% span and 100% flow intersect at the upper right hand corner of the chart. Move down to 90% span, make it 9.0, and multiply it by itself. Move now to the 90% flow mark and make a prominent dot at the point where 90% flow intersects with 81, the result of multiplying 9 × 9. Move on to 80%, multiply 8 × 8 to get 64 and match that with the 80% flow line. Continue down the span column inserting a decimal and multiplying each % of span figure by itself and matching it with its corresponding % of flow. Make all dots prominent, and then connect the dots with a line to give the chart a profile like that in Figure 1.

HANDOUT #1

FIGURE 1

ΔP Flow Chart



The chart in Figure 1 illustrates the non-linear flow going into a square root extractor. Since the % of span is expressed in increments of 10% and the span is 12, then each 10% increment would have a value of .12. Multiplying each span increment by .12 provides the reference needed for the psi conversion. After multiplying each increment by .12, add 3 because 3 equals zero since the span is 3-15 psi. After adding 3 to each 10% increment multiplied by .12, the chart in Figure 2 reflects the psi value of the non-linear signal from the output of the differential pressure transmitter.

HANDOUT #1

FIGURE 2

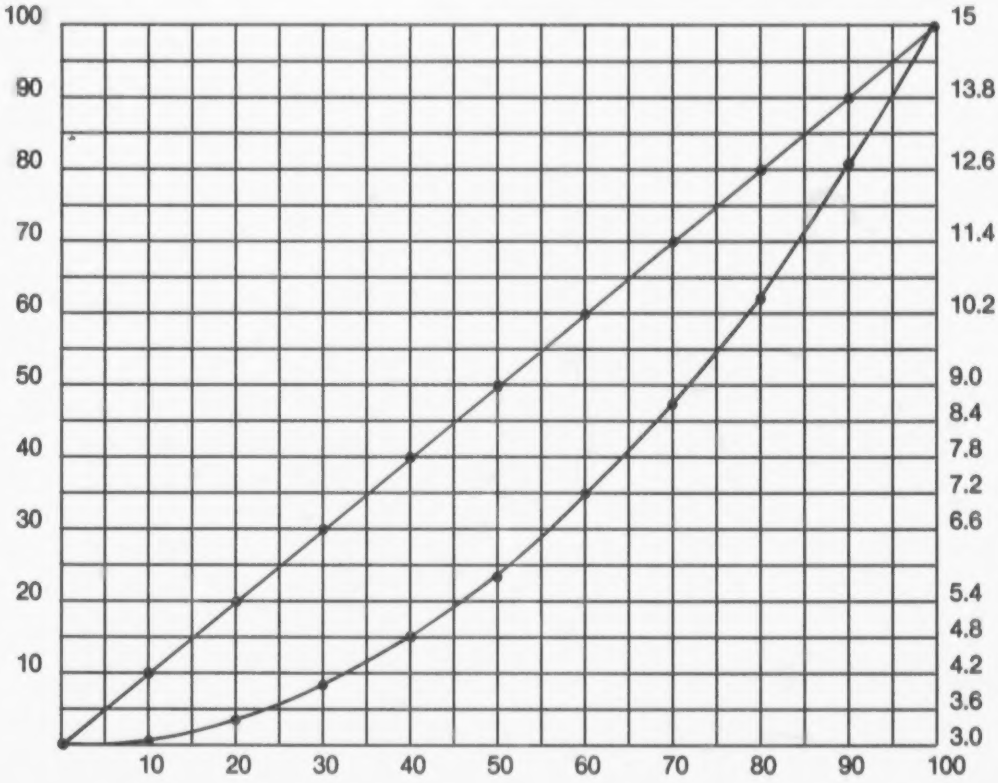
% Flow			ΔP % Span					PSI
100	10 × 10	=	100	× .12	12.00	+ 3	=	15.00
90	9 × 9	=	81	× .12	9.72	+ 3	=	12.72
80	8 × 8	=	64	× .12	7.68	+ 3	=	10.68
70	7 × 7	=	49	× .12	5.88	+ 3	=	8.88
60	6 × 6	=	36	× .12	4.32	+ 3	=	7.32
50	5 × 5	=	25	× .12	3	+ 3	=	6.00
40	4 × 4	=	16	× .12	1.92	+ 3	=	4.92
30	3 × 3	=	9	× .12	1.08	+ 3	=	4.08
20	2 × 2	=	4	× .12	.48	+ 3	=	3.48
10	1 × 1	=	1	× .12	.12	+ 3	=	3.12
0	0 × 0	=	0	× .12	0	+ 3	=	3.0

Extracting the square root

In the square root extractor, the square root of each input value is extracted so that the non-linear signal is converted to a linear signal. The conversion to the linear signal becomes obvious when compared to the non-linear input as demonstrated in the chart in Figure 3.

HANDOUT #1

FIGURE 3



Conclusion

Converting non-linear signals to psi values is a quick way to assure proper signals are being output from a differential pressure transmitter. Consequently, troubleshooting and calibrating a square root extractor can be accomplished properly because the proper linear signal from the square root extractor is based on the appropriate non-linear input. This example uses the psi conversion, but the same procedure can be used to make the mA conversion for the 4-20 mA standard.

SIGNAL CONDITIONING
UNIT IV

JOB SHEET #1 — CALIBRATE A PNEUMATIC SQUARE ROOT EXTRACTOR

A. Tools and materials

1. Safety glasses
2. Square root extractor (Moore Model 65 or equivalent)
3. Regulator (Moore model 40-30 or equivalent)
4. U.S. gauge (F500)
5. Pneumatic calibrator, 0-30 psi (Wallace and Tiernan Series 65-120)
6. Plastic tubing and connections
7. Basic hand tools
8. Pencil

B. Routine #1 — Pre-testing the square root extractor

1. Put on safety glasses.
2. Connect bench air to air supply on calibrator.
3. Exercise the pneumatic calibrator.
4. Return selector switch to vent after exercising the calibrator.
5. Turn bench air OFF.
6. Refer to Figure 1 as you complete the remainder of this routine.
7. Connect hose from P-1 to the input signal on the square root extractor.
8. Connect hose from P-2 to the supply on the square root extractor.
9. Connect hose P-3 to the output signal on the square root extractor.
10. Vent port "S" to atmosphere.
11. Place selector switch to vent.
12. Turn regulators 1 and 2 counterclockwise to set them at zero pressure.

JOB SHEET #1

13. Remove the sour screws holding the cover, and take the face cover off the extractor.

14. Find the two set screw wrenches located inside the cover, and place them aside for later adjustments that may be required.

15. Turn bench air on and check for leaks.

16. Set the selector switch on the calibrator to position P-2.

17. Use regulator #2 to supply the calibrator with 20 psi, and leave the regulator set for this pressure during the entire calibration procedure.

    (NOTE: Refer to Handout #1 as needed to make proper entries on the data charts and graphs that accompany this job sheet.)

18. Turn the selector switch to P-3 to read the output of the extractor.

19. Turn the selector switch to P-1 and adjust regulator #1 to 10% or 3.12 psi, and enter the information on the pre-calibration data chart that accompanies this job sheet.

20. Move the selector switch to P-3, and read and record the extractor output.

    (NOTE: Most instrument calibration begins at 0% or 3 psi to match the standard, but based on the characteristics of square root extraction, the accuracy of the lower scale lends itself to a greater error than the middle and upper scale readings do, so the 0% reading is not used.)

21. Return selector switch to P-1, and adjust to 6 psi.

22. Move selector switch to P-3, and read and record extractor output on Pre-Calibration Data Chart #1.

23. Return selector switch to P-1, and adjust to 15 psi.

24. Move selector switch to P-3, and read and record extractor output.

25. Plot a graph to show your pre-calibration information on Pre-Calibration Graph #1.

    (NOTE: Before you begin graphing your data, you may want to review Handout #1 "The Five-Point Check" in Unit II. It contains guidelines for converting percentages to psi.)

26. Decide which type of error is present, and mark your selection:

    Zero ____________

    Span ____________

    ☐ Have your instructor check your pre-testing routine.

C. Routine #2 — Calibrating the square root extractor

   1. Put on safety glasses.

JOB SHEET #1

2. Adjust input pressure to 3.12 psi.

3. Check for output pressure of 4.20:

   a. If output pressure is not 4.20 psi, loosen the zero lock screw, and turn the zero adjustment out to raise the output pressure.

   b. If output pressure is high, turn the zero adjustment screw in to lower output pressure.

4. Tighten zero lock screw after setting zero adjustment.

5. Adjust the input pressure to 6 psi.

   (NOTE: Change the selector switch back and forth as needed to get all input/output readings.)

6. Check for an output pressure of 9 psi, and note the output on Post-Calibration Chart #1.

7. Adjust the input pressure to 15 psi.

8. Check for an output pressure of 15 psi, and note the output of your post-calibration chart.

9. Complete the Post Calibration Graph on Data Sheet #1.

   a. If the calibration error is within +.06 and −.06 psi, no deviation adjustment is necessary.

   b. If the calibration is not within the above limits, make a deviation adjustment.

10. Calculate the deviation according to the formula shown in Figure 2 that accompanies this job sheet, and note the results:

    Positive quantity ______________

    Negative quantity ______________

11. Loosen the deviation lock screw located below the slotted deviation adjustment bushing.

    a. If your calculation showed a positive quantity, turn the slotted adjustment bushing OUT.

    b. If your calculation showed a negative quantity, turn the slotted adjustment bushing IN.

JOB SHEET #1

12. Tighten the deviation lock screw after making the adjustment.
13. Readjust the zero, recheck input/output readings, and chart and graph all information on Post Calibration Chart #2 and Graph #2.
14. Calculate the error again, if required, and continue until the deviation error is within calibration limits.

    ☐ Have your instructor check work.

D. Routine #3 — Calibrating span

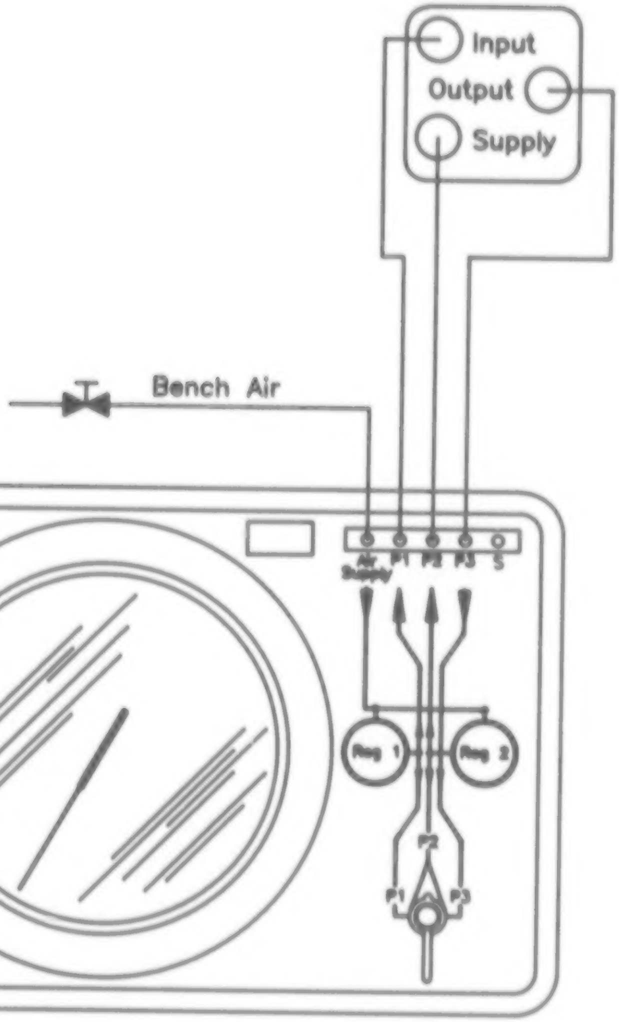
1. Put on safety glasses.
2. Verify that zero and deviation adjustments have been properly completed.
3. Set the input pressure to 6 psi.
4. Check for an output pressure of 9 psi, and note the reading on Post-Calibration Chart #3.
5. Set the input pressure to 15 psi.
6. Check for an output pressure of 15 psi, and enter the reading on post Calibration Chart #3.
7. Make span adjustments according to the following:
    a. If output span needs to be increased, loosen the span lock screws, and move the span adjustment lever to the left.
    b. If span needs to be decreased, move the span adjustment lever to the right.
8. Tighten both span lock screws after making the span adjustment.
9. Recheck zero and span.
10. Continue calibration procedures previously outlined until the extractor is within calibration limits of +.06 and −.06 psi in the 3-15 psi range.
11. Plot Post-Calibration graph #3 to verify proper output.

    ☐ Have your instructor check work.

12. Disconnect and secure the calibrator.
13. Clean area, and return equipment and materials to proper storage.

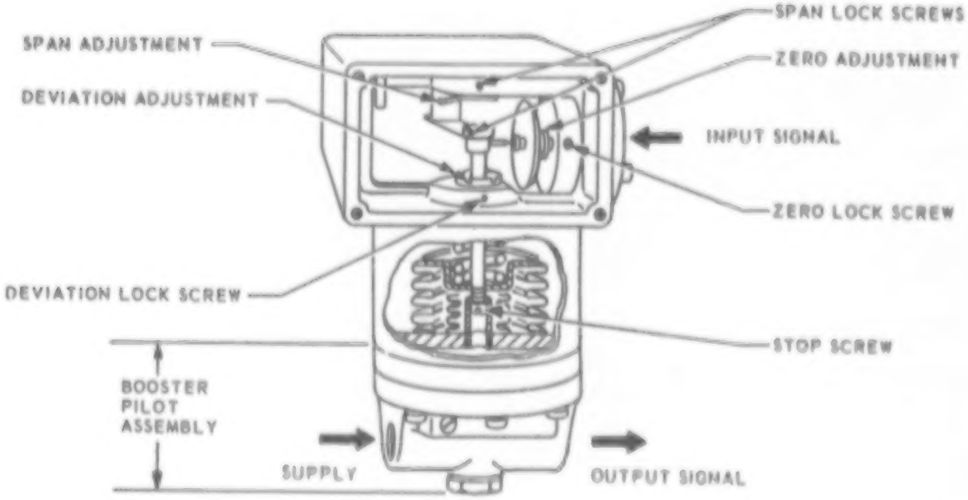
JOB SHEET #1

FIGURE 1


Input
Output
Supply
Bench Air
Air Supply
P1
P2
P3
S
Reg 1
Reg 2
P2
P1
P3

JOB SHEET #1

FIGURE 2


SPAN ADJUSTMENT
DEVIATION ADJUSTMENT
DEVIATION LOCK SCREW
BOOSTER PILOT ASSEMBLY
SUPPLY
SPAN LOCK SCREWS
ZERO ADJUSTMENT
INPUT SIGNAL
ZERO LOCK SCREW
STOP SCREW
OUTPUT SIGNAL

$$\text{Deviation Error} = \text{Error at half-scale} - \frac{\text{Error at full-scale}}{2}$$

EXAMPLE:

Model 65 Input PSIG	Standard Output PSIG	Model 65 Output PSIG	Error PSIG
3.12	4.20	4.20	0
6.00	9.00	10.50	1.5
15.00	15.00	15.50	0.5

$$\begin{aligned} \text{D.E.} &= +1.5 - \frac{(+0.5)}{2} \\ &= +1.5 - (+0.25) \\ &= +1.5 + (-0.25) \\ &= +1.25 \end{aligned}$$

Courtesy Moore Products Company

JOB SHEET #1

Calibration Data Sheet

Technician's Name: ______________________ Title: __________

Standard Used: ______________________________

Manufacturer: ______________________ Serial #: __________

Instrument Calibrated: ______________________________

Manufacturer: ______________________ Serial #: __________

Date: ______________________ Field ☐ Bench ☐

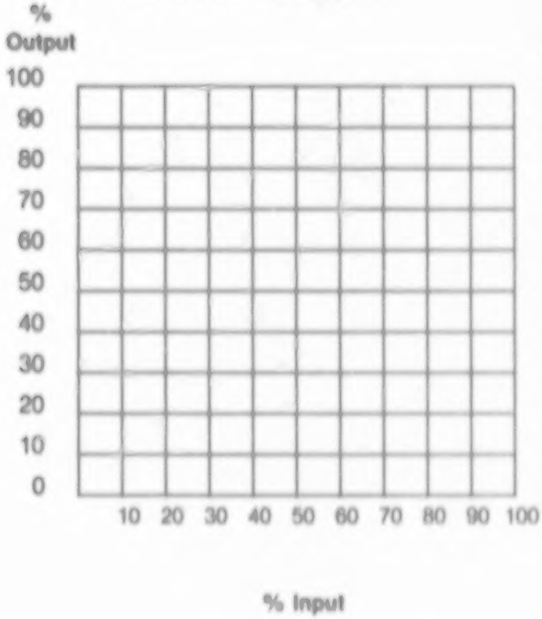
Pre-Calibration Data Chart #1

% Input	Pneumatic Calibrator Setting in H_2O	Sq. Rt. Ext. Output in PSI
100		
50		
10		

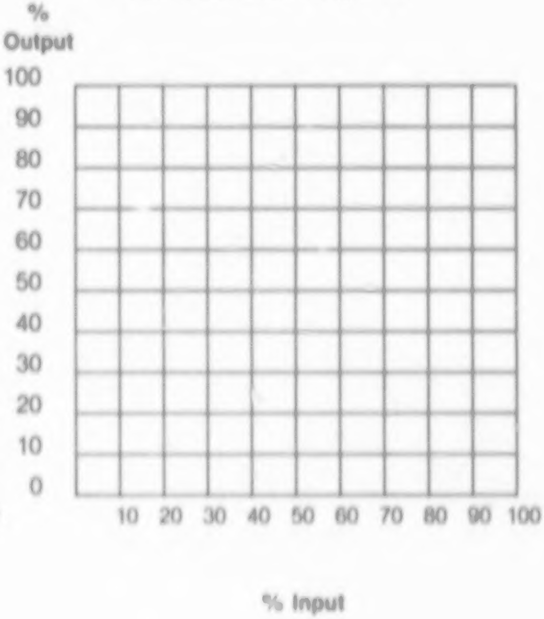
Post-Calibration Data Chart #1

% Input	Pneumatic Calibrator Setting in H_2O	Sq. Rt. Ext. Output in PSI
100		
50		
10		

Pre-Calibration Graph #1



Post-Calibration Graph #1



JOB SHEET #1

Calibration Data Sheet

Technician's Name: ______________________________ Title: ______________

Standard Used: ____

Manufacturer: ______________________________ Serial #: ______________

Instrument Calibrated: ____

Manufacturer: ______________________________ Serial #: ______________

Date: ______________________________ Field ☐ Bench ☐

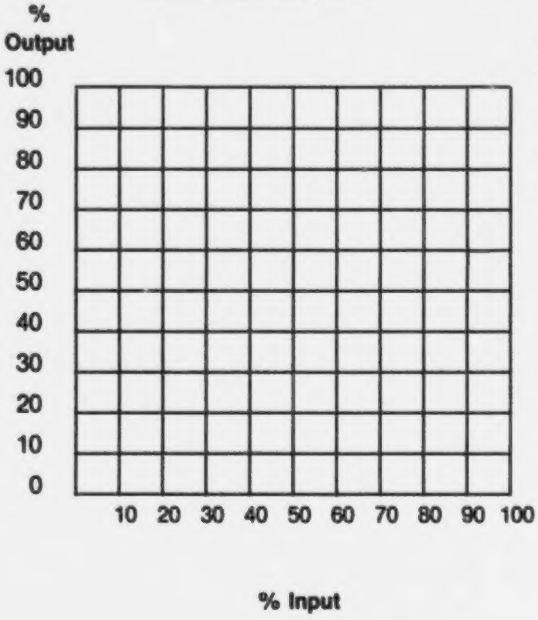
Calibration Data Chart #2

% Input	Pneumatic Calibrator Setting in H_2O	Sq. Rt. Ext. Output in PSI
100		
50		
10		

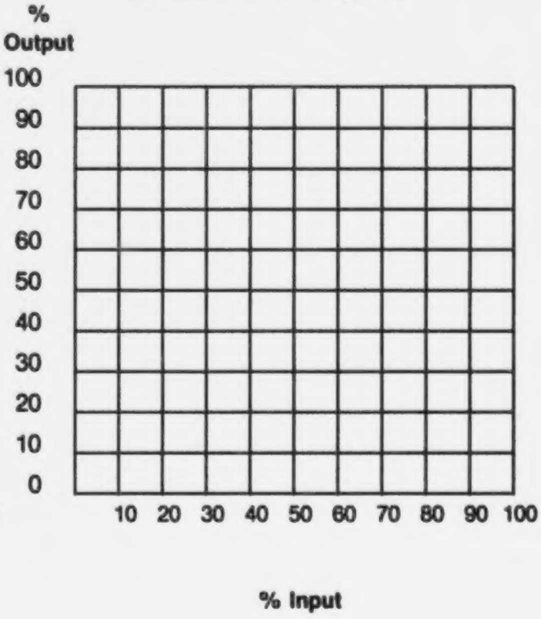
Post-Calibration Data Chart #3

% Input	Pneumatic Calibrator Setting in H_2O	Sq. Rt. Ext. Output in PSI
100		
50		
10		

Calibration Graph #2



Post-Calibration Graph #3



SIGNAL CONDITIONING
UNIT IV

JOB SHEET #2 — CALIBRATE A MULTI-FUNCTION COMPUTING RELAY

A. Equipment and materials

1. Safety glasses
2. Basic hand tools
3. Multi-function computing relay (Moore Model 68-1 or equivalent)
4. Pneumatic calibrator (Wallace and Tiernan, Series 65-120)
5. Plastic tubing and connections
6. Tee connections (2)
7. Pencil

B. Routine #1 — Calibrating for a $T = A + B - C$ function

(NOTE: Where T = output, the relay function subtracts input C from the totals of inputs A and B.)

1. Put on safety glasses.
2. Connect bench air supply to the air supply connection on the pneumatic calibrator.
3. Vent outlet S to atmosphere, and set regulators #1 and #2 to 0 psi.
4. Exercise the pneumatic calibrator, and if it operates properly, set regulator #1 to 0 and turn bench supply air off.
5. Connect P-1 on the calibrator to the supply connection on the relay.

   (NOTE: Be sure to refer to Figure 1 that accompanies this job sheet.)
6. Connect P-2 to all three relay ports by using two tees.
7. Connect the relay output to P-3 on the calibrator.
8. Turn on bench air, and check for leaks.
9. Turn selector valve to P-1.

JOB SHEET #2

10. Adjust regulator #1 supply air to 20 psi, and leave the pressure at 20 psi for the entire calibration.

11. Turn selector valve to P-2.

12. Adjust regulator #2 to 3 psi.

13. Adjust bias screw until relay output is 3 psi.

14. Adjust regulator #2 to 15 psi.

15. Check for a relay output of 15 psi.

    a. If relay output is low, turn the tracking adjustment clockwise until properly adjusted.

    b. If relay output is high, turn the tracking adjustment counterclockwise until properly adjusted.

16. Repeat the procedure as required until the calibration is correct.

    ☐ Have your instructor check your work.

17. Turn off bench air, and disassemble test apparatus.

C. Routine #2 — Calibrating for a T = B − C function

(NOTE: Where T = output, the relay function subtracts input C from input B.)

1. Put on safety glasses.

2. Connect P-2 to ports 2 and 3 of the relay with a tee connection.

   (NOTE: Refer to Figure 2 that accompanies this job sheet.)

3. Connect the relay output to P-3 on the calibrator.

4. Turn on bench air, and check for leaks.

5. Adjust regulator #1 supply air to 20 psi, and leave it there.

6. Turn selector valve to P-2.

7. Adjust regulator #2 to 3 psi.

8. Adjust bias screw until relay output is 9 psi.

9. Adjust regulator #2 to 15 psi.

JOB SHEET #2

10. Check for relay output of 9 psi.
    a. If relay output is low, turn the tracking adjustment clockwise until properly adjusted.
    b. If relay output is high, turn the tracking adjustment counterclockwise until properly adjusted.
11. Repeat the procedure as required until the calibration is correct.

    ☐ Have your instructor check your work.

D. Routine #3 — Calibrating for T = −C function

(NOTE: Where T = output, the relay function causes the output to have a negative value in relation to input C so that 3 psi input gives a 15 psi output, and a 15 psi input gives a 3 psi output, so that the instrument functions as a reversing relay.)

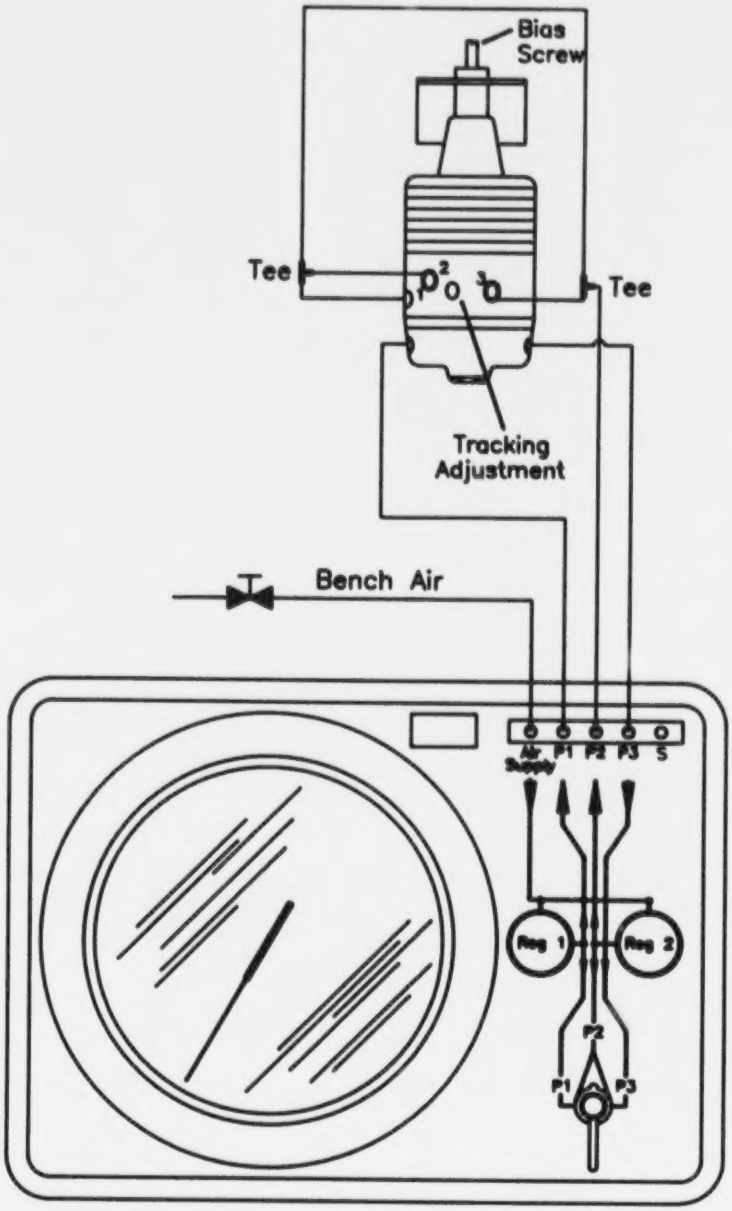
1. Put on safety glasses.
2. connect P-2 to port #3 on the relay.

   (NOTE: Refer to Figure 3 that accompanies this job sheet.)
3. connect the relay output to P-3 on the calibrator.
4. Turn on bench air, and check for leaks.
5. Adjust regulator #1 supply air to 20 psi, and leave it there.
6. Turn selector valve to P-2.
7. Adjust regulator #2 to 3 psi.
8. Adjust bias screw until relay output is 15 psi.
9. Adjust regulator #2 to 15 psi.
10. Check for a relay output of 3 psi.
    a. If relay output is low, turn the tracking adjustment counterclockwise until properly adjusted.
    b. If relay output is high, turn the tracking adjustment clockwise until properly adjusted.
11. Repeat the procedure as required until calibration is correct.

    ☐ Have your instructor check your work.
12. Turn off bench air, disassemble test apparatus, and secure the calibrator.
13. Clean area, and return equipment and materials to proper storage.

JOB SHEET #2

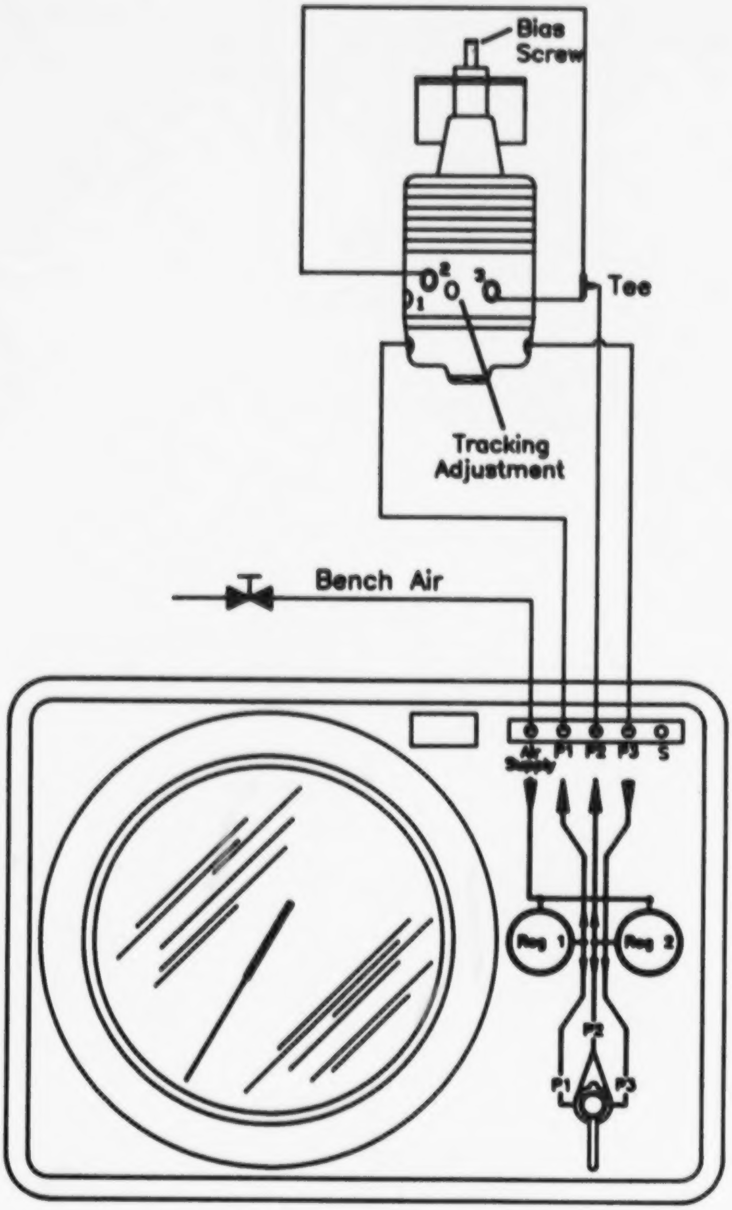
FIGURE 1


Bias Screw
Tee
Tee
1
2
3
Tracking Adjustment
Bench Air
Air Supply
P1
P2
P3
S
Reg 1
Reg 2
P2
P1
P3

T (output) = A + B − C (inputs)

JOB SHEET #2

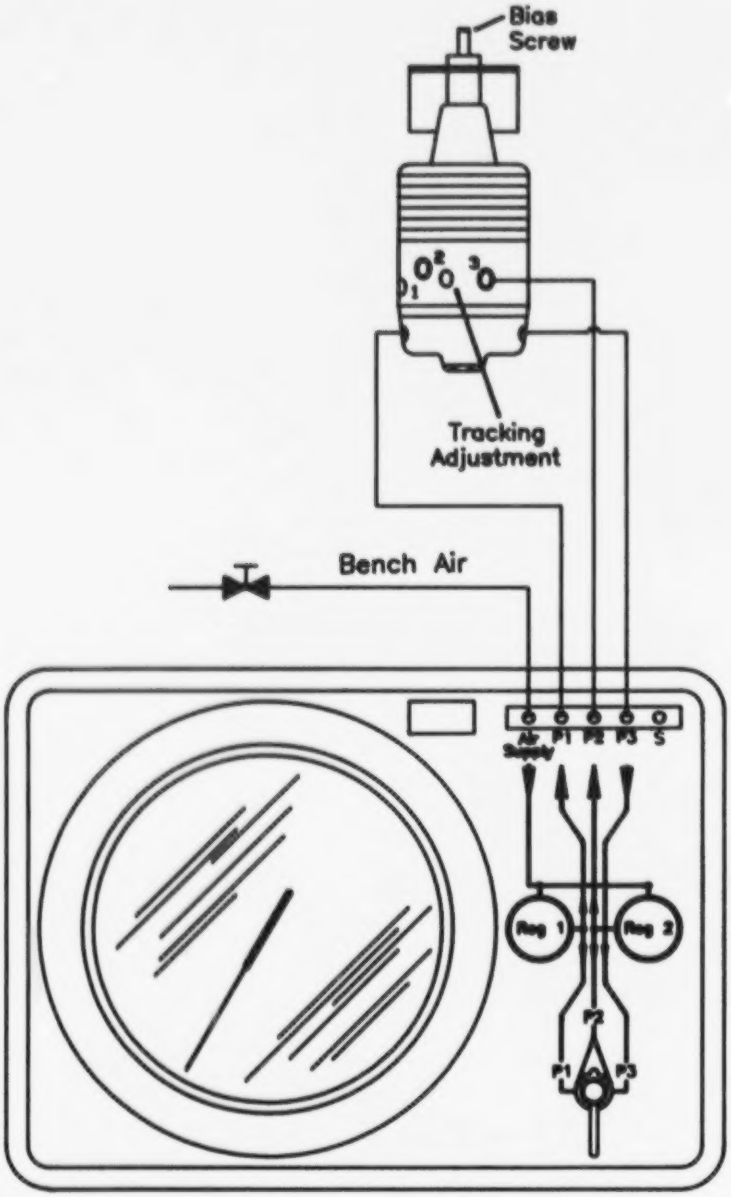
FIGURE 2


Bias Screw
1
2
3
Tee
Tracking Adjustment
Bench Air
Air Supply
P1
P2
P3
S
Reg 1
Reg 2
P2
P1
P3

T (output) = B − C (inputs)

JOB SHEET #2

FIGURE 3


Bias Screw
1
2
3
Tracking Adjustment
Bench Air
Air Supply
P1
P2
P3
S
Reg 1
Reg 2
P2
P1
P3

T (output) = −C (input)

SIGNAL CONDITIONING
UNIT IV

JOB SHEET #3 — CALIBRATE A CURRENT-TO-PRESSURE TRANSDUCER

A. Equipment and materials

1. Safety glasses
2. I/P transducer (Taylor 1400T or equivalent)
3. Decade resistance box and electrical leads
4. DVOM and electrical leads
5. Pneumatic calibrator (Wallace and Tiernan 65-125)
6. 24V DC power supply and electrical leads
7. Plastic tubing and connections
8. Basic hand tools
9. Pencil

B. Routine #1 — Setting up the test equipment

1. Put on safety glasses.
2. Arrange the equipment similar to the configuration shown in Figure 1 that accompanies this job sheet.
3. Pay special attention to the polarity of the transducer and all other equipment used in the job sheet.
4. Set your DVOM for a range that will measure 4-20 mA.
5. Set the decade resistance box for approximately 6,000 ohms to obtain the 4 mA current input to the transducer.

   (NOTE: Approximately 1,200 ohms will equal 20 mA.)
6. Connect the P-1 calibrator connection to the supply of the I/P transducer.
7. Connect the output of the transducer to P-3 on the calibrator.

   ☐ Have your instructor check your setup.

JOB SHEET #3

C. Routine #2 — Pretesting the I/P transducer

1. Put on safety glasses.

2. Turn the 24 VDC power supply on and quickly check your DVOM to make sure the reading is in the 4-20 mA range.

3. Turn power off immediately if the range is improper.

   (NOTE: If readings are not within the 4-20 mA range, check the polarity of the entire circuit, check to make sure the decade resistance box is properly set, and make sure all connections are tight; if necessary, ask your instructor for help.)

4. Adjust the decade resistance box for a reading of 4 mA on the DVOM.

5. Turn the selector switch on the pneumatic calibrator to P-3 and read the output of the I/P transducer.

6. Adjust the decade resistance box for a reading of 10% current input or 5.6 mA.

7. Record your 10% psi output reading on your pre-calibration data chart that accompanies this job sheet.

8. Adjust the decade resistance box for a reading of 30% current input or 8.4 mA and record the psi output reading on the pre-calibration chart.

9. Adjust the decade resistance box for a reading of 50% current input or 12.0 mA, and record the psi output reading on the pre-calibration chart.

10. Adjust the decade resistance box for a reading of 70% current input or 15.2 mA, and record the psi otuput reading on the pre-calibration chart.

11. Adjust the decade resistance box for a reading of 90% current input or 18.4 mA, and record the psi output reading on the pre-calibration chart.

12. Plot the pre-calibration data on the pre-calibration graph that accompanies this job sheet.

    ☐ Have your instructor check your work.

D. Routine #3 — Calibrating and post-testing the I/P transducer

1. Put on safety glasses.

2. Make sure the selector switch on the pneumatic calibrator is still set at P-3.

3. Adjust the decade resistance box for a 4mA input into the transducer.

JOB SHEET #3

4. Turn the zero adjustment until the output reads 3 psi.

   (NOTE: The zero adjustment screw is clearly marked and easily adjusted with a screwdriver.)

5. Adjust the decade resistance box for a 20 mA input into the transducer.

6. Turn the span adjustment until the output reads 15 psi.

7. Check to make sure that your 3 psi reading is within a tolerance of +0.02 or −0.02, and that the 15 psi reading is within a tolerance of +0.06 or −0.06.

8. Repeat zero and span adjustments as required to obtain output accuracy.

9. Complete a five-point check and enter the input/output figures on your post-calibration chart.

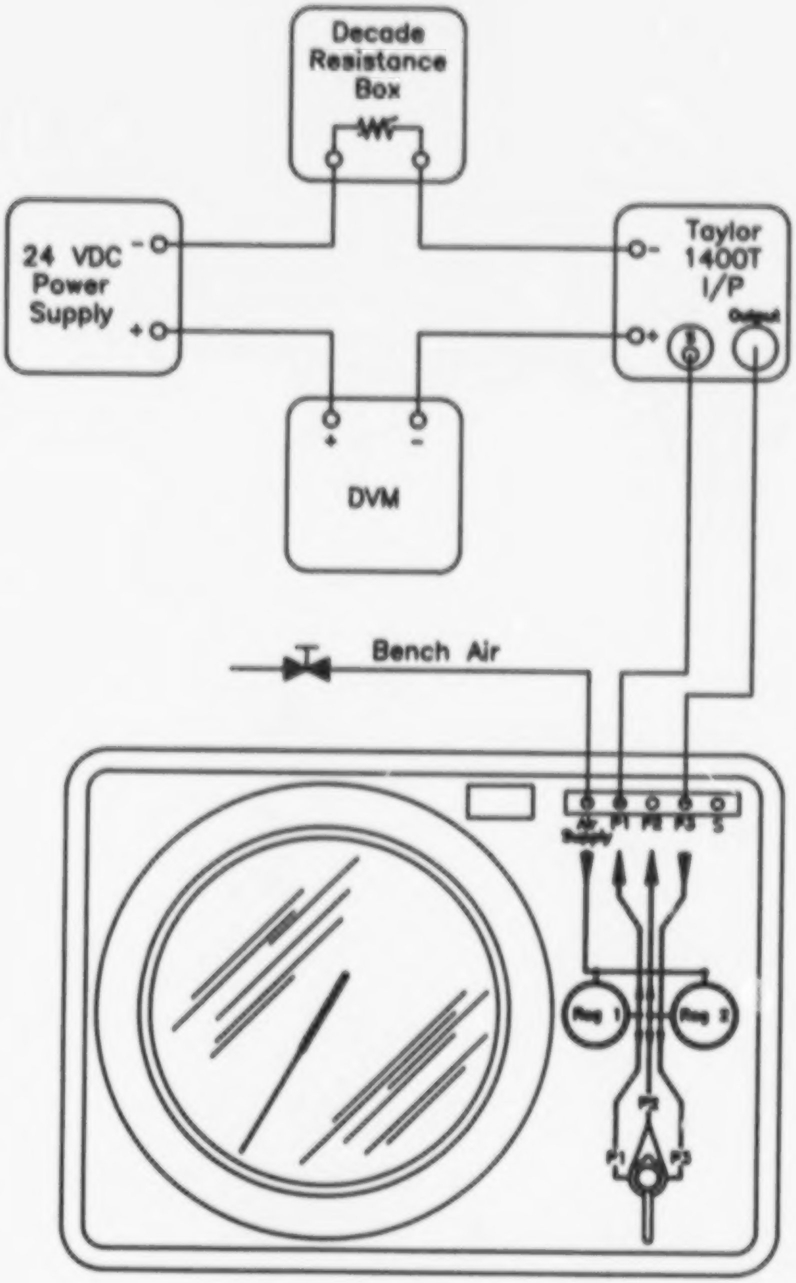
10. Graph your post-calibration data.

    ☐ Have your instructor check your work.

11. Dismantle test apparatus and return equipment to proper storage.

JOB SHEET #3

FIGURE 1


Decade Resistance Box
24 VDC Power Supply
-
+
Taylor 1400T I/P
-
+
Output
+
-
DVM
Bench Air
Air Supply
P1
P2
P3
S
Reg 1
Reg 2
P2
P1
P3

JOB SHEET #3

Calibration Data Sheet

Technician's Name: ______________________________ Title: ______________

Standard Used: ____

Manufacturer: ______________________________ Serial #: ______________

Instrument Calibrated: ____

Manufacturer: ______________________________ Serial #: ______________

Date: ______________________________ Field ☐ Bench ☐

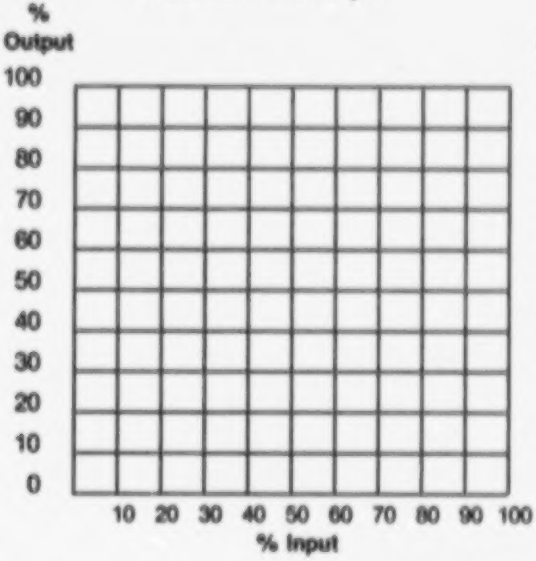
Pre-Calibration Data Chart

% Input	Pneumatic Calibrator Setting in H_2O	I/P Output in PSI
90		
70		
50		
30		
10		

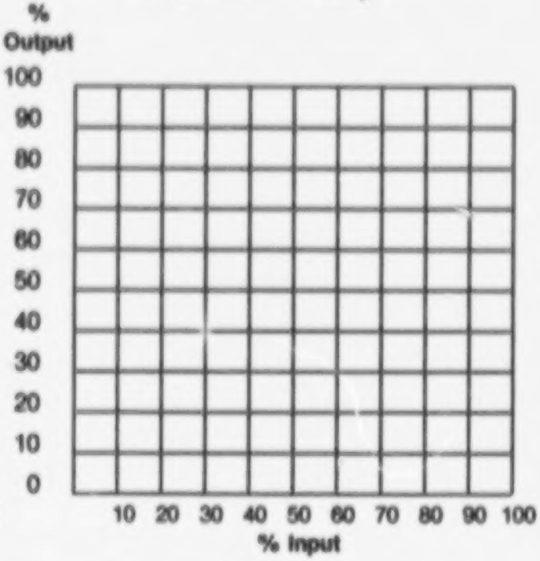
Post-Calibration Data Chart

% Input	Pneumatic Calibrator Setting in H_2O	I/P Output in PSI
90		
70		
50		
30		
10		

Pre-Calibration Graph



Post-Calibration Graph



SIGNAL CONDITIONING
UNIT IV

PRACTICAL TEST #1
JOB SHEET #1 — CALIBRATE A PNEUMATIC SQUARE ROOT EXTRACTOR

Student's name ______________________________ **Date** ____________

Evaluator's name ____________________________ **Attempt no.** ______

Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Pretested square root extractor properly.	1.	☐	☐
2. Recorded output readings on pre-test graph.	2.	☐	☐
3. Calibrated extractor properly.	3.	☐	☐
4. Prepared calibration graph to show deviation.	4.	☐	☐
5. Made span adjustment properly.	5.	☐	☐
6. Made zero adjustment properly.	6.	☐	☐
7. Observed personal and equipment safety.	7.	☐	☐
8. Returned equipment and materials to proper storage.	8.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #1 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Equipment and Materials	Properly selected and properly used 4	Properly selected and acceptably used 3	Poorly selected and/or used 2	Improperly selected and/or used 1
Calibrating Procedure	Well followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Data Recording	All properly entered 4	Almost all entered 3	Too few entered 2	Too few entered or improperly entered 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ____

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

SIGNAL CONDITIONING
UNIT IV

PRACTICAL TEST #2
JOB SHEET #2 — CALIBRATE A MULTI-FUNCTION COMPUTING RELAY

Student's name ______________________ **Date** __________

Evaluator's name ______________________ **Attempt no.** _____

Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Connected and exercised pneumatic calibrator.	1.	☐	☐
2. Calibrated properly for a $T = A + B - C$ function.	2.	☐	☐
3. Set up calibrator properly.	3.	☐	☐
4. Calibrated properly for a $T = B - C$ function.	4.	☐	☐
5. Set up calibrator properly.	5.	☐	☐
6. Calibrated properly for a $T = -C$ function.	6.	☐	☐
7. Observed personal and equipment safety.	7.	☐	☐
8. Returned equipment and materials to proper storage.	8.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #2 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Equipment and Materials	Properly selected and properly used 4	Properly selected and acceptably used 3	Poorly selected and/or used 2	Improperly selected and/or used 1
Calibrating Procedure	Well followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Data Recording	All properly entered 4	Almost all entered 3	Too few entered 2	Too few entered or improperly entered 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ____________________

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

SIGNAL CONDITIONING
UNIT IV

PRACTICAL TEST #3
JOB SHEET #3 — CALIBRATE A CURRENT-TO-PRESSURE TRANSDUCER

Student's name ________________________ **Date** __________

Evaluator's name ________________________ **Attempt no.** _____

Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Pretested transducer properly.	1.	☐	☐
2. Recorded outputs on data sheet.	2.	☐	☐
3. Calibrated transducer.	3.	☐	☐
4. Recorded post-calibration output readings.	4.	☐	☐
5. Plotted post-test on calibration sheet.	5.	☐	☐
6. Observed personal and equipment safety.	6.	☐	☐
7. Returned equipment and materials to proper storage.	7.	☐	☐

Evaluator's comments: ______________________________________

____

____

JOB SHEET #3 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Equipment and Materials	Properly selected and properly used 4	Properly selected and acceptably used 3	Poorly selected and/or used 2	Improperly selected and/or used 1
Calibrating Procedure	Well followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Data Recording	All properly entered 4	Almost all entered 3	Too few entered 2	Too few entered or improperly entered 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ____

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

SIGNAL CONDITIONING
UNIT IV

TEST

NAME ________________________________ SCORE ______________

1. Match the terms on the right with their correct definitions.

_____a. A compact housing for an electronic device, including its interface connections for other components in a system

_____b. A high-gain, linear IC that receives two (AC or DC) input signals and amplifies the difference between the two signals to accomplish mathematical functions such as subtracting and inverting

_____c. Changing an analog voltage to a binary level

_____d. An output module or subsystem that receives binary output from a computer and changes it to an analog signal

_____e. A general reference to a category of electronic devices ranging from simple diodes to sophisticated ICs whose circuitry is embedded in silicone or other crystalline material for the purpose of controlling electron flow

1. Quantizing
2. Solid state
3. Module
4. Recovery system
5. OP AMP

2. Select true statements concerning the objectives of signal conditioning by placing an "X" beside each statement that is true.

_____a. The preparation of a signal for use in a controller or other process equipment is known as signal conditioning.

_____b. Signal conditioning has always been an important part of process systems, but has become even more important as systems move into controls that are based on integrated circuits, or systems that are computer based.

_____c. Signal conditioning can range from a level change in the transfer of energy from a sensor to a transmitter on to the analog to digital conversion that prepares an analog signal for computer control.

_____d. Signal conditioning is applicable only to electrical systems.

TEST

_____e. Electrical systems present diverse problems in electronic control signal conditioning, and because of the trend toward computerized controls, these devices and subsystems merit special attention.

_____f. The types of circuits used to condition analog electronic signals have their counterparts in some pneumatic devices, but there is no pneumatic counterpart for digital electronics because what can be accomplished with air circuits would be impractical in terms of cost, size, and response time.

3. Complete statements concerning pneumatic relays by circling the material that best completes each statement.

   a. Pneumatic relays modify pneumatic signals, (**but they do not change pneumatic signals to other forms, and they change pneumatic signals to other forms**).

   b. A volume booster increases air (**pressure, volume**) without increasing air (**volume, pressure**), and is often used where increased air (**volume, pressure**) is needed to operate a final element.

   c. Pneumatic (**computing, math**) relays perform complex calculations such as adding, subtracting, averaging, or multiplying signals.

   d. Computing relays usually work with (**more than one, only one**) input to compute a new value; a square root extractor is a good example of a computing relay.

   e. Amplifying relays change a signal level in accordance with a fixed ratio such as 2 to 1 or 3 to 1, and these relays are also called (**variable, ratio**) relays.

   f. A reversing relay (**modifies, reverses**) an input signal to (**its opposite, another**) value such as receiving a 3 psi input and reversing it to 15 psi.

   g. A reducing relay usually reduces an input signal on a (**variable, fixed**) ratio of 1 to 2 or 1 to 3.

4. Solve problems concerning electrical ratio conditioning by selecting the correct answer.

   a. Electrical ratio conditioners might also be called what, relays or amplifiers?

      Answer: ______________________________

   b. AC and DC signals ratio up or down with what, the same equipment or transformers are used for AC signals and amplifiers and attenuators are used for DC signals.

      Answer: ______________________________

TEST

5. Solve problems concerning A/D signal conditioning by selecting the correct answer.

   a. A/D signal conditioners are necessary because most sensors and transducers produce an analog signal, and a computer can work only with what, binary signals or decimal signals?

      Answer: ______________________________

   b. Analog signals have to be samples in a time sequence before they can be converted, and this activity begins with what, an analog relay or a multiplexer?

      Answer: ______________________________

6. Solve problems concerning D/A signal conditioning by selecting the correct answer.

   a. After a compute receives an A/D signal it must convert the signal back to an analog signal in order to what, keep sensors in balance or run the final element and other linear devices in the system?

      Answer: ______________________________

   b. To complete the D/A conversion a resistance network is connected to computer output so that each binary output is transformed to an analog value through a process that assigns what, weighted values to each binary output or direct analog conversion to each binary output?

      Answer: ______________________________

7. Solve problems concerning current-to-pressure signal conditioning by selecting the correct answer.

   a. Most I/P systems are used to interface electrical controller signals with what, the air motor that drives a control valve or the linear devices in a system?

      Answer: ______________________________

   b. The I/P conversion is typically what, a flapper/nozzle system or a step-up transformer?

      Answer: ______________________________

TEST

8. Select true statements concerning voltage-to-current signal conditioning by placing an "X" beside each statement that is true.

_____a. Since the output of many transducers is an electrical voltage instead of current, a voltage-to-current converter is used to convert voltage into the 4-20 mA standard signal.

_____b. In older systems, the task of voltage to current conversion was reasonably complex because the DC input signal was chopped to form an AC signal which was fed into a voltage-to-current transformer, and this current signal was rectified back to DC to produce the 4-20 mA standard signal.

_____c. In modern systems the voltage-to-current conversion is accomplished by one integrated circuit which is an OP-AMP.

_____d. The OP-AMP circuit is characterized by high input impedance, and very low output impedance, making it a natural voltage-to-current converter.

_____e. The OP-AMP gain can be set externally by a pair of resistors, and this makes it easy to set the proportion of voltage input to produce the 4-20 mA standard output signal.

9. Solve problems concerning calibrating signal conditioners by selecting the correct answer.

a. Generally speaking, testing a signal conditioner means supplying a test bench input such as a generator and measuring the output with what, a DVOM, or a meter or an oscilloscope as the system requires.

Answer: ____________________

b. D/A and A/D converters are modular or IC packages and standard procedures can be used for calibration, but with non-modular systems, circuit boards have to be tested with what, DVOM and decade resistance box or signal generator and oscilloscope?

Answer: ____________________

10. Select true statements concerning maintenance of signal conditioners by placing an "X" beside each statement that is true.

_____a. Although the I/P converter must be periodically cleaned and adjusted, most signal conditioners are modular, must be checked for proper operation according to an appropriate schedule, and replaced if they develop a problem.

_____b. What few mechanical relays that are left require virtually no maintenance.

_____c. Points on mechanical relays should be dressed with a point file, a tension gauge should be applied to the relay armature, and a bending tools should be used to bend the spring enough to set proper tension.

TEST

11. Solve problems concerning troubleshooting signal conditioners by selecting the correct answer.

    a. Routine troubleshooting of signal conditioners usually consists of what, a good visual inspection or measuring the signal in and out?

       Answer: ______________________________

    b. In the case of digital A/D and D/A converters, troubleshooting requires what special instrument, a digital probe or an oscilloscope?

       Answer: ______________________________

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

12. Demonstrate the ability to:

    a. Calibrate a pneumatic square root extractor. (Job Sheet #1)

    b. Calibrate a multi-function computing relay. (Job Sheet #2)

    c. Calibrate a current-to-pressure transducer. (Job Sheet #3)

SIGNAL CONDITIONING
UNIT IV

ANSWERS TO TEST

1. a. 3
   b. 5
   c. 1
   d. 4
   e. 2

2. a, b, c, e, f

3. a. But do not change pneumatic signals to other forms
   b. Volume, pressure, volume
   c. Computing
   d. More than one
   e. Ratio
   f. Reverses
   g. Fixed

4. a. Amplifiers
   b. Transformers are used for AC signals and amplifiers and attenuators are used for DC signals

5. a. Binary signals
   b. A multiplexer

6. a. Run the final element and other linear devices in the system
   b. Weighted values to each binary output

7. a. The air motor that drives a control valve
   b. A flapper/nozzle system

8. a, b, c, d, e

9. a. A meter or an oscilloscope as the system requires
   b. Signal generator and oscilloscope

10. a, c

ANSWERS TO TEST

11. a. Measuring the signal in and out
    b. An oscilloscope

12. a. Evaluated according to criteria in Practical Test #1
    b. Evaluated according to criteria in Practical Test #2
    c. Evaluated according to criteria in Practical Test #3

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss principles of final element operations, and relate actuators, positioners, and control valves to their functions in a process system. The student should also be able to classify flow characteristics of control valves and discuss valve plugs, cages, trim, and packing as they relate to control valve performance. The student should also be able to disassemble, inspect, and reassemble a control valve, adjust valve plug travel and range on an actuator, replace an actuator diaphragm, and replace a seat-ring on a globe-type control valve. These competencies will be evidenced by correctly completing the procedures outlined in the job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to actuators, positioners, and control valves with their correct definitions.
2. Match parts of a control valve with their functions.
3. Complete statements concerning control valve characteristics.
4. Solve problems concerning flow characteristics of control valves.
5. Select true statements concerning cages.
6. Complete statements concerning valve plug guiding.
7. Solve problems concerning restricted-capacity valve trim.
8. Solve problems concerning valve plugs with groove pins.
9. Select true statements concerning packing.
10. Select true statements concerning packing lubrication.
11. Match basic control valve types with their characteristics.
12. Complete statements concerning other types of valves.

OBJECTIVE SHEET

13. Solve problems concerning control valve end connections.

14. Solve problems concerning extension bonnets.

15. Select true statements concerning guidelines for control valve maintenance.

16. Solve problems concerning diaphragm actuators.

17. Complete statements concerning electromechanical actuators.

18. Select true statements concerning piston actuators.

19. Complete statements concerning handwheel and handlever actuators.

20. Select true statements concerning valve positioners.

21. Solve problems concerning safety in control valve/actuator service.

22. Complete statements concerning troubleshooting control valve/actuator subsystems.

23. Select true statements concerning troubleshooting other final elements.

24. Demonstrate the ability to:

    a. Disassemble, inspect, and reassemble a globe-type control valve. (Job Sheet #1)

    b. Adjust valve plug travel on an actuator. (Job Sheet #2)

    c. Adjust range on an actuator. (Job Sheet #3)

    d. Replace the diaphragm on an air-to-lower actuator. (Job Sheet #4)

    e. Replace the seat-ring on a globe-type control valve. (Job Sheet #5)

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information sheet.

C. Make transparencies.

D. Demonstrate and discuss the procedures outlined in the job sheets.

E. Invite a technician who specializes in valve repair to talk to the class about problems that have to be solved in repair activity.

F. Invite a manufacturer's representative to talk to the class about control valve design, the types of control valves used at process industries in your area or state, and how positioners and other accessories are used to improve control valve operation.

G. Arrange a visit to a facility where students can see how a service bypass is installed in actual operating conditions, and try to arrange for a technician to demonstrate how the service bypass is put into operation.

H. Review elements of safety required with valve/actuator service, and impress upon students the importance of wearing eye protection.

I. Have available as many different types of valves as possible, and show disassembled valves so students can visually identify cages, plugs, trim, packing, and other important valve components.

J. Give test.

REFERENCES USED IN DEVELOPING THIS UNIT

A. *Control Valve Handbook*. Fisher Controls Company. Marshalltown, IA 50158: Fisher Controls Company, 1977.

B. *Types 7SA and 7SAR Electromechanical Actuators*. Marshalltown, IA 50158: Fisher Controls Company, 1980.

C. *Type 1066 and 1066SR On-Off Piston Rotary Actuators*. Marshalltown, IA 50158: Fisher Controls Company, 1984.

D. *Instruction, Hi-Flow™ Valve with Lin-E-Aire® Actuator*. 95 Ames Street, Rochester, NY 14601: Taylor Instrument Company, 1981.

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

INFORMATION SHEET

I. **Terms and definitions**

A. Final element — That part of a process system which responds to controller output in order to maintain a controlled variable at setpoint

B. Control valve — A valve designed for service as a final element

C. Bonnet assembly — That part of a valve through which a valve plug stem moves, which contains a means for sealing against leakage along the stem, and which provides a means for attaching an actuator

D. Packing box — That part of a bonnet assembly used to seal against leakage around the valve plug stem

E. Valve plug — A movable part which provides a variable restriction in a valve port

F. Valve plug stem — A rod extending through a valve bonnet assembly to permit positioning of the valve plug

G. Valve plug guide — That portion of a valve plug which aligns plug movement in either a seat-ring, bonnet, bottom flange, or any two of these

H. Trim — The internal parts of a valve which come in contact with flowing fluid

I. On/Off valve — A control valve designed to operate at one of two positions, fully open or fully closed

J. Throttling valve — A control valve designed to operate between the limits of fully open or fully closed

K. Cavitation — A phenomena that occurs when fluid pressure rises above vapor pressure of a fluid, causing entrained bubbles to collapse and damage valve components

L. Flashing — A phenomena that occurs when fluid pressure drops below vapor pressure of a fluid and produces bubbles which remain in the fluid and damage valve components

M. Noise attenuation — The modification or addition of valve trim to control hydrodynamic noise resulting from liquid flow or aerodynamic noise resulting from the turbulent flow of gas

INFORMATION SHEET

II. **Parts of a control valve and their functions** (Transparency 1)

A. Valve body — A housing with inlet and outlet flow connections that serves also to house internal parts, and to which external parts are attached

B. Bonnet assembly — An assembly that includes the part through which the valve plug stem moves, and a means for protecting the stem from leaking

C. Bottom flange — A part which closes a valve body opening opposite the bonnet assembly

D. Valve plug — A movable part that provides a variable restriction in a plug

E. Valve plug stem — A rod extending through the bonnet assembly to permit positioning of the valve plug

F. Valve plug guide — That part of a valve plug which aligns its movement with a seat ring, bonnet, bottom flange, or any two of these

G. Seat ring — A piece inserted into a valve body to form a valve body port

H. Yoke — A structure by which the diaphragm or cylinder assembly is supported rigidly on the bonnet assembly

I. Packing box — That area inside the bonnet into which the packing and packing springs are placed

J. Packing — Material inserted around a valve plug stem to prevent the stem from leaking

K. Packing spring — A spring situated below the packing so that it exerts pressure upward on the packing

L. Packing box bushing — A device that holds the packing spring and helps guide the valve plug stem through the bonnet assembly

M. Packing follower — A bushing-like material placed between the packing and the packing flange to help assure a tight packing seal

N. Packing flange — A flange that fits on top of the bonnet and is secured with studs and nuts to seal the top over the packing follower

III. **Control valve characteristics**

A. Control valves are also classified according to how they open and close in response to actuator action: (Transparency 2)

1. A push-down-to-close valve closes as the actuator moves the valve stem plug down on the seat ring to close the valve.

INFORMATION SHEET

2. A push-down-to-close control valve is also called a direct acting valve.

3. A push-down-to-open valve opens as the actuator moves the valve stem plug away from the seat ring to open the valve.

4. A push-down-to-open control valve is also called a reverse acting valve.

B. Another control valve classification concerns the position of the valve port in the event of actuator power failure:

1. In a fail-closed valve, the port remains closed when actuator power fails.

2. In a fail-open valve, the port remains open when actuator power fails.

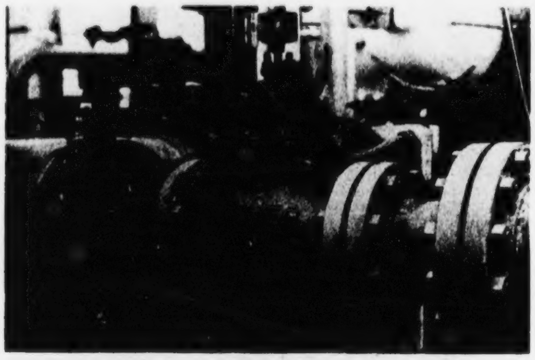
3. In a fail-safe valve, the valve plug will fully close the port, fully open the port, or remain in a fixed position according to actuator design as dictated by the system.

4. If a hazardous condition would result with input is too high, the valve should fail low.

5. If a hazardous condition would result with input too low, the valve should fail high.

C. A control valve has a flow arrow on the body, and the valve should be installed so that the flow is in the direction of the arrow. (Figure 1)

FIGURE 1



D. Some control valves without flow arrows will have "IN" and "OUT" stamped on the flanges.

INFORMATION SHEET

E. Flow leading into a control valve is said to be "upstream," and flow going away from the control valve is said to be "downstream."

F. Control valves generally are on/off valves or "throttling" valves that control flow in between the limits of fully open or fully closed.

IV. **Flow characteristics of control valves**

A. The flow characteristics of a globe-style control valve is determined by the contour of the valve plug surface and the way it fits into the seat ring.

B. There are two types of flow characteristics:

1. An inherent flow characteristics occurs when a constant pressure drop is maintained across a control valve.

2. An installed flow characteristics occurs when pressure drop across a control valve varies in relation to conditions in a system.

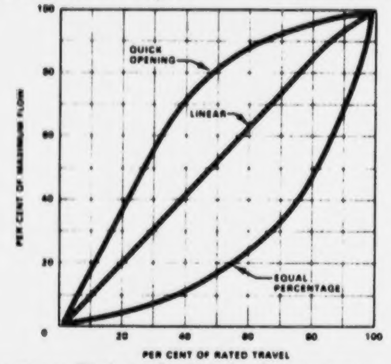
C. In a valve with an inherent linear flow characteristics, equal increments of travel yield equal increments of flow at a constant pressure drop.

D. In a valve with inherent equal percentage flow characteristic, equal increments of rated travel should give equal percentage changes in flow.

E. In a valve with inherent quick opening flow characteristics, there is maximum flow with minimum travel.

F. When the three types of inherent flow are presented graphically, the profile shows how each type of flow relates percent of travel to the percent of maximum flow. (Figure 2)

FIGURE 2



Courtesy Fisher Controls Company

G. The flow characteristics of a valve pretty much determine what kind of service the valve can accomplish:

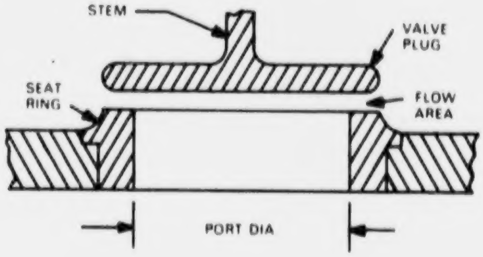
1. Valves with linear flow characteristics are often used for liquid level control.

INFORMATION SHEET

2. Valves with equal percentage flow characteristics are used on pressure control applications, and situations where highly varying pressure drops can be expected.

3. Valves with quick opening flow characteristics are typically used for on/off applications where high volume flow rate must be established quickly, and quick opening valves are often used as relief valves. (Figure 3)

FIGURE 3



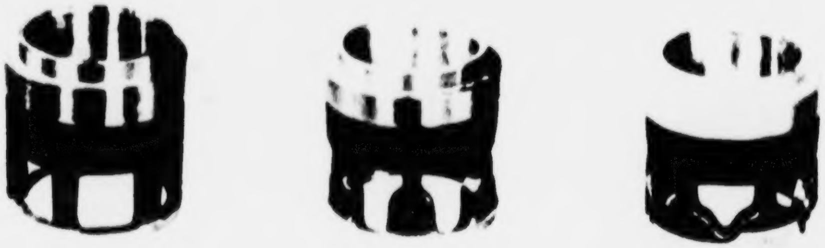
Courtesy Fisher Controls Company

V. Cages

A. A cage is a hollow cylindrical trim element that serves as a guide to align movement of a valve plug with a seat ring.

B. Standard cages are available to produce linear, equal percentage, and quick opening flow characteristics in a control valve. (Figure 4)

FIGURE 4



Quick Opening **Linear** **Equal Percentage**

Courtesy Fisher Controls Company

INFORMATION SHEET

C. The advantage of a cage-guided valve is that the flow characteristics can be changed by installing a different cage; the valve plug and seat ring do not usually have to be changed.

D. Another advantage of cage-guided valves is that special cage designs are available to provide noise attenuation or control cavitation.

VI. Valve plug guiding

A. Valve plug guiding is required to assure that the valve plug stem moves smoothly through its travel range and to assure that the valve plug provides the correct valve plug/seat ring alignment when the valve closes.

B. Top-and-bottom guiding is accomplished with one bushing in the bonnet of the valve, and a second bushing in the bottom flange.

C. Top guiding is accomplished with a single bushing in the valve body bonnet.

D. Top-and-port guiding is accomplished with a guide bushing in the bonnet and by the valve port body; small diameter valve plugs to control low flow rates are often designed with top-and-port guiding.

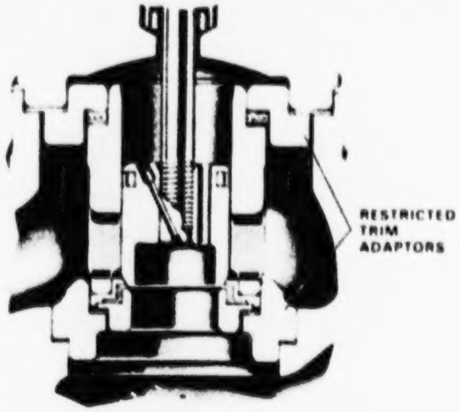
E. Stem guiding is accomplished with a guide bushing in the bonnet that acts directly on the valve plug stem.

F. Cage guiding is built in because the outside diameter of the valve plug is in close tolerance with the inside service of the valve body throughout the range of travel.

VII. Restricted-capacity valve trim

A. Conventional globe-style valve bodies can be fitted with seat rings with smaller-than-normal port size, and valve plugs designed to fit the smaller ports. (Figure 5)

FIGURE 5



Courtesy Fisher Controls Company

INFORMATION SHEET

B. Restricted-capacity trim is used primarily to reduce inlet and outlet fluid velocities in valve bodies that are over-sized through design error, or in larger valve bodies selected for their structural strength.

C. Reduced-capacity service is not at all unusual in instrumentation because the special trim provides design and service options:

1. It permits selection of a valve body large enough for future flow requirements, but the trim can be sized for present needs.

2. It can eliminate the need for expensive pipeline reducers.

D. Technicians servicing restricted-capacity trim will find it similar to other trim service because trim parts are usually from a smaller valve of similar construction with adaptor pieces above the cage and below the seat ring so that the smaller parts mate with the valve body.

VIII. Valve plugs with groove pins

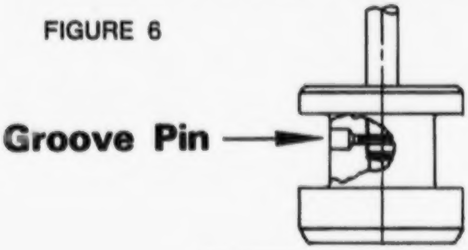
A. When a valve stem is assembled into a valve plug, it should be screwed in until it wedges tight at the end of the valve stem threads.

B. When a valve stem is screwed into a plug, it needs to be further secured with a groove pin, and the hole for the groove pin has to be drilled.

C. There is a pilot hole in the valve plug to serve as a guide for drilling the groove pin hole which must be drilled to specifications, and a matching groove pin must be used.

D. The diameter of the valve stem connection determines what size drill must be used, and what size groove pin should be used. (Figure 6)

FIGURE 6



VSC* (In.)	Drill Size (In.)	Groove Pin
3/8	3/32	1B5991 3507
1/2	1/8	1B5996 3507
3/4	3/16	1F7236 3507
1 & 1-1/4	1/4	1D2697 3507

*Valve Stem Connection

Courtesy Fisher Controls Company

INFORMATION SHEET

IX. **Packing** (Transparency 3)

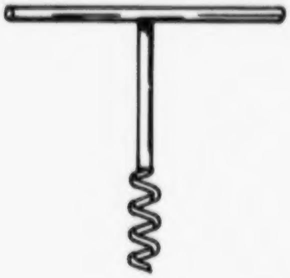
A. Packing is material positioned around the valve plug stem to prevent the valve bonnet from leaking, and because packing is subject to wear, replacing packing is a job that almost every technician faces from time to time.

B. Generally, packing is either lubricated graphite, spring-loaded graphite, or TFE in square cross-sections or V-rings.

(NOTE: TFE is a variety of Teflon®.)

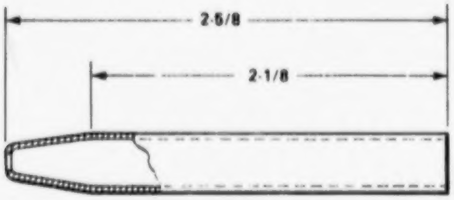
C. When removing old packing, corkscrew tools are normally used, but they have to be handled with care to avoid damaging the valve stem. (Figure 7)

FIGURE 7



D. For installing new packing, packing tools are recommended because they slide down over the stem threads and permit a technician to tamp the packing in place without damaging the stem threads. (Figure 8)

FIGURE 8



Courtesy Taylor Instrument Company

INFORMATION SHEET

E. TFE packing should never be pounded into place, and all packing should be placed in order according to manufacturer's specifications.

EXAMPLE: Spring-loaded packing uses a wiper ring, and lubricated graphite packing use a lantern ring to permit lubrication to enter into the packing when packing is lubricated in service. (Transparency 3)

F. With TFE V-ring packing, the packing nut should be tightened down as far as it will go before putting the valve back in service.

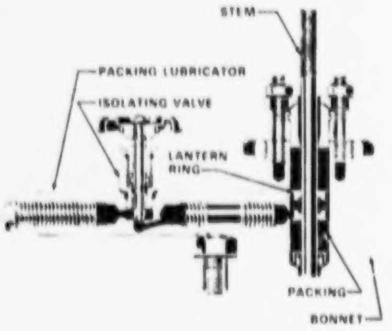
G. With graphite packing, the packing nut should be screwed hand tight, and then tightened as required after the valve has been put back in service.

H. Silicone grease is a commonly used packing lubricant, but in all cases, lubrication should follow manufacturer's specifications.

X. Packing lubrication

A. Semi-metallic packing and graphited asbestos around a valve stem requires lubrication, and this is accomplished by removing the pipe plug and installing a lubricator or a lubricator/isolating valve. (Figure 9)

FIGURE 9



Courtesy Fisher Control Company

B. There are special lubricants for standard service, high temperature service, and chemical service, and manufacturer's specifications for lubrication should be carefully followed.

C. With a standard lubricator, the lubricant is placed in the lubricator and the lubricator bolt is turned clockwise to force lubricant into the packing.

D. With a lubricator/isolating valve used in high pressure service, the isolating valve has to be opened to permit lubrication, and should be closed immediately after each lubrication.

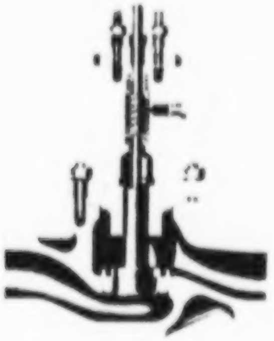
INFORMATION SHEET

E. The type of lubricant and dates of lubrication should be recorded on the control valve service record so it will become a part of the control valve service history.

XI. Basic control valve types and their characteristics

A. Single-port valve bodies — The most common body style, and generally specified for applications with stringent shutoff requirements. (Figure 10)

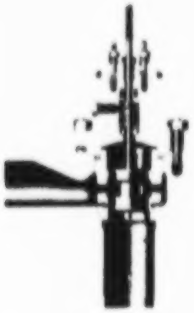
FIGURE 10



Courtesy Fisher Controls Company

B. Angle-style valve bodies — These valves are usually single-ported, often used in boiler feedwater and heater drain service, and can also serve as an elbow. (Figure 11)

FIGURE 11

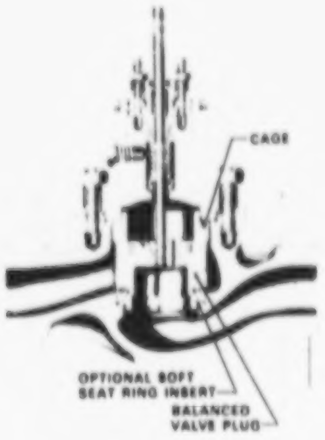


Courtesy Fisher Controls Company

INFORMATION SHEET

C. Balanced-plug cage-style valve bodies — Single-ported valves that require smaller actuators than other single-ported bodies, and permit trim selection for specific flow characteristics. (Figure 12)

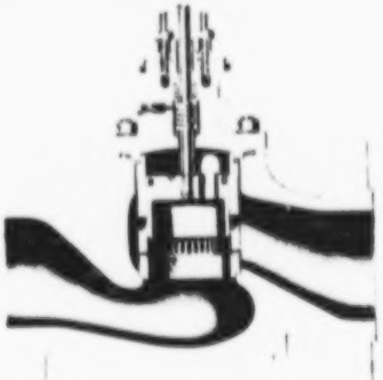
FIGURE 12


CAGE
OPTIONAL SOFT SEAT RING INSERT
BALANCED VALVE PLUG

Courtesy Fisher Controls Company

D. High-capacity cage-guided valve bodies — These valves have oversize end connections, and are designed for noise applications such as high pressure gas reducing stations. (Figure 13)

FIGURE 13

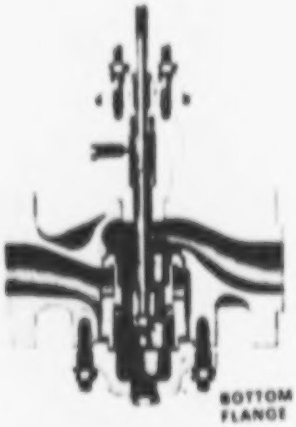


Courtesy Fisher Controls Company

INFORMATION SHEET

E. Reverse-acting cage-guided valve bodies — This is a modification of the cage-guided body so that the valve can be used when push-down-to-open valve plug action is desired. (Figure 14)

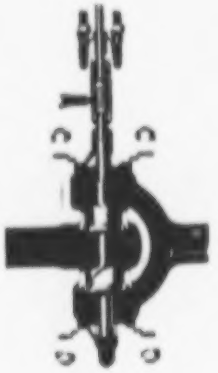
FIGURE 14



Courtesy Fisher Controls Company

F. Double-ported valve bodies — These valves reduce dynamic forces on the valve plug and can be used in high pressure drop applications or other severe service conditions with a smaller actuator than would be required on a single-ported valve. (Figure 15)

FIGURE 15

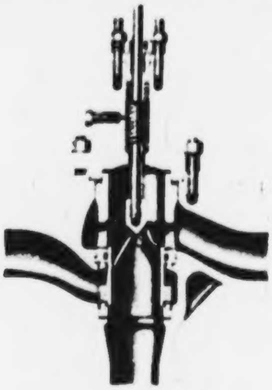


Courtesy Fisher Controls Company

INFORMATION SHEET

G. Three-way valve bodies — A special valve design that can provide flow-mixing or flow-splitting, and often designed with cage trim for ease of maintenance. (Figure 16)

FIGURE 16



Courtesy Fisher Controls Company

XII. **Other types of valves**

A. Butterfly valve bodies provide high capacity with low pressure loss through the valve.

B. Butterfly valves are economical, especially in larger sizes, but may require high output actuators if the valve is big or the pressure drop is high. (Figure 17)

FIGURE 17

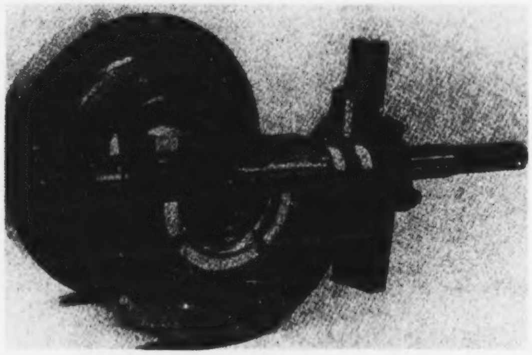
Courtesy Fisher Controls Company

INFORMATION SHEET

C. V-notch ball control valve bodies have a straight through flow design that produces little pressure drop.

D. V-notch valves are good for handling errosive fluids or slurries containing fibers or entrained solids, and are widely used in chemical plants, the paper industry, sewage treatment plants, power plants, and petroleum refineries. (Figure 18)

FIGURE 18

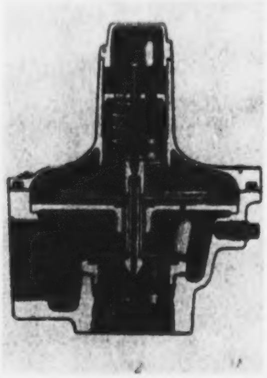


Courtesy Fisher Controls Company

E. Eccentric-disc control valve bodies are relatively new, but the disc design and operation minimizes seal wear; they are adaptable to many control applications, and are often less costly than globe-style valves of equal capacity.

F. Relief valves come in many shapes and sizes, and as the name implies, they are used to vent pressure from service lines. (Figure 19)

FIGURE 19

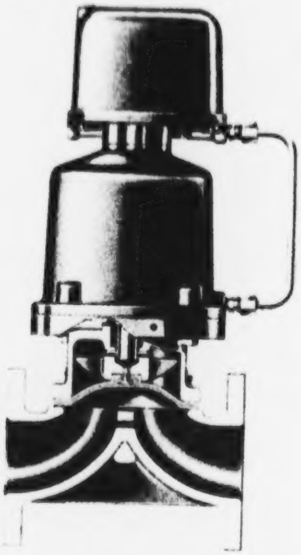


Courtesy Fisher Controls Company

INFORMATION SHEET

G. Pinch valves are typically used for service with slurries where entrained solids in a medium would quickly wear out other types of valves. (Figure 20)

FIGURE 20



Courtesy Fisher Controls Company

XIII. **Control valve end connections**

A. The three common methods for installing control valves in pipelines are:

1. By using screwed pipe threads;
2. By using bolted gasketed flanges;
3. By welding the end connections.

B. Screwed pipe threads cost less than flanged ends, and they can be used on valves up to 2 inches.

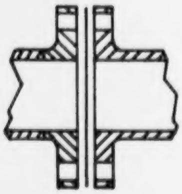
C. Screwed pipe threads are not recommended for high temperature service, and pose maintenance problems because a flanged joint or coupling has to be broken elsewhere to remove the valve.

INFORMATION SHEET

D. Bolted gasketed flanges are used on all sizes of valves:

1. The flat face flange is commonly used in low pressure, cast iron, and brass valves. (Figure 21)

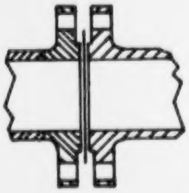
FIGURE 21



Courtesy Fisher Controls Company

2. The raised-face flange is finished with circular grooves for good sealing and resistance to gasket blowout, and is used for pressures up to 6,000 psig, and temperatures up to 1500°F. (Figure 22)

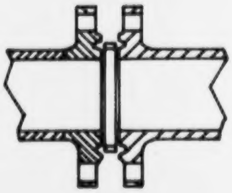
FIGURE 22



Courtesy Fisher Controls Company

3. The ring-type joint flange has a U-shaped groove with a metal ring gasket that wedges into each side as the flange is tightened to provide an extra-tight seal. (Figure 23)

FIGURE 23



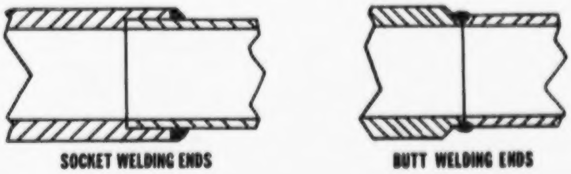
Courtesy Fisher Controls Company

4. Ring-type joint flanges are excellent in high pressure applications up to 15,000 psig, but are not often used in high temperature applications.

INFORMATION SHEET

E. Welded end connections may have socket welding ends or butt welding ends. (Figure 24)

FIGURE 24



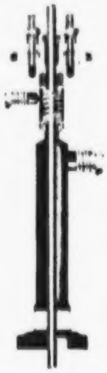
Courtesy Fisher Controls Company

F. Welded end connections are leak-proof at all pressures and temperatures, but they are difficult to remove from a line.

XIV. Extension bonnets

A. For both high temperature and low temperature service, control valves use an extension bonnet between the packing box and the bonnet flange. (Figure 25)

FIGURE 25



Courtesy Fisher Controls Company

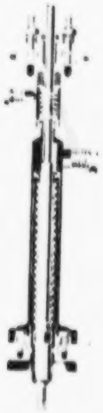
B. High temperature control valves usually use a cast extension to provide better heat emission and a better cooling effect.

INFORMATION SHEET

C. Low temperature control valves usually use an extension fabricated from stainless steel because it has a lower capacity for thermal conductivity than carbon steel.

D. Bellows seal extension bonnets are used when process fluids are toxic or volatile, and both the stem and valve packing have to be protected from the process fluid. (Figure 26)

FIGURE 26



Courtesy Fisher Controls Company

E. Plugs in extension bonnets can be used to purge the valve body and bonnet of process fluid, and in the case of a bellows seal extension, any leakage from the plug indicates that the bellows seal is broken and requires replacement.

XV. Guidelines for control valve maintenance

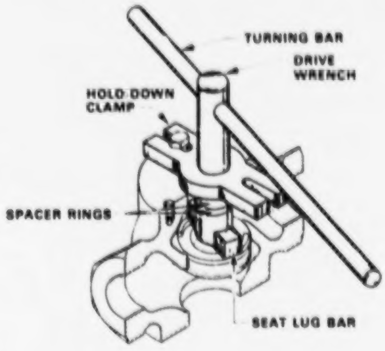
A. Always be certain that all line pressure is shut off and released from the valve body, and also be certain that all pressure to the actuator is cut off and captive pressure gradually relieved.

B. When replacing stem packing, make sure there is no pressure in the valve body before starting to remove the packing nuts. (See Job Sheet #1)

INFORMATION SHEET

C. Seat rings are subjected to wear, especially in severe service conditions, and a seat ring puller should always be used on threaded seats. (Figure 27 and Job Sheet #5)

FIGURE 27

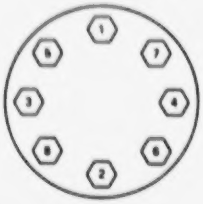


Courtesy Fisher Controls Company

D. Lapping or grinding metal seats in globe valves will normally restore good valve plug closing, and the grinding can be accomplished with readily available grinding compounds and a site-made grinding tool.

E. Snug up flange bolts gently at first to assure proper flange alignment, then tighten the bolts in a criss-cross pattern to avoid uneven gasket loading or damage to the flange. (Figure 28)

FIGURE 28



Courtesy Fisher Controls Company

F. On valves with screwed connections, use a good grade of pipe sealant on the male threads only, but do not use sealant on the female threads in the valve body because excess sealant could be forced into the valve body and impair its performance.

INFORMATION SHEET

XVI. **Diaphragm actuators**

A. There are four basic types of actuators:

1. Diaphragm actuators;
2. Piston actuators;
3. Electro-hydraulic actuators;
4. Manual actuators.

B. Diaphragm actuators are operated pneumatically with air from a controller, positioner, or other source.

C. Diaphragm actuators use molded diaphragms that can be replaced with relative ease and speed, and diaphragm actuators are the most common types in use because of their simple construction, dependability, and economy.

D. Diaphragm actuators are generally classified as air-to-lower (direct acting) or air-to-raise (reverse acting). (Transparencies 4 and 5)

XVII. **Electromechanical actuators** (Transparency 6)

A. Electromechanical actuators are driven by either ac or dc motors, and they are frequently used to actuate large valves because they can deliver extremely high thrust and high torque.

B. An assortment of accessories for electromechanical actuators permits them to be used with both sliding stem and rotary control valves.

C. In modern electromechanical actuators, the torque and limit switches that control stem movement are readily accessable inside the switch compartment cover, and both torque and limit can be set with a screwdriver.

D. Manual handwheels are often integrated on electromechanical actuators with lever-operated clutches that permit override of the power operation in the event manual control of the valve is ever needed or desired.

XVIII. **Piston actuators**

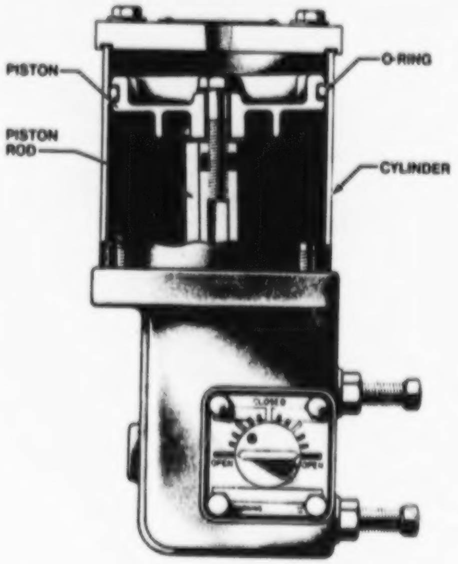
A. Piston actuators are also pneumatically operated, and usually operate at high pressure to provide maximum thrust output and quick response.

B. Piston actuators are in common use with butterfly valves, and on rotary-shaft control valves.

INFORMATION SHEET

C. Piston actuators are used mostly in applications that require positive on/off valve service, but can also be used with a positioner for throttling service. (Figure 29)

FIGURE 29



Courtesy Fisher Controls Company

XIX. Handwheel and handlever actuators

A. Handwheel and handlever actuators provide a manual means for controlling control valves and other valves, and both types see service in all sorts of industrial applications.

B. Handwheel actuators have special travel indicators, some marked in $^{1}/_{64}$" graduations to provide precise valve positioning, and a good visual indication of valve position to take guesswork out of manual operation.

C. Manual rotary actuators are designed for use on rotary-shaft valve bodies, butterfly valve bodies, and ball valve bodies.

D. As with the valves they service, manual rotary actuators are either direct acting or reverse acting, and travel indicators and direction of operation are clearly marked on the actuator housing. (Transparency 7)

E. Handlever actuators are used on spline-shaft rotary valves, ball valves, and butterfly valves and provide accurate positioning for specific flow requirements.

INFORMATION SHEET

XX. **Valve positioners** (Transparency 8)

A. When an air-operated control valve/actuator cannot respond to very small changes in diaphragm pressure, a pneumatic valve positioner is used to enhance valve positioning.

B. Because of a feedback arrangement from the control valve, a positioner has the sensitivity needed to react to very small changes in pressure and accomplish valve stem movement with speed and precision.

C. Since some valves are designed for other than the 3-15 psi standard, a valve positioner can be used to compensate for non-standard service.

EXAMPLE: It is not uncommon for a control valve to start opening at 7 psi (instead of 3 psi) and be fully closed at 15 psi. To be compatible with a standard 3-15 psi output, a positioner would be used to compensate for the difference in range value.

D. In a split-range application where two ro more control valves are responding to output from a single controller, a positioner permits each valve to respond to a given range.

E. Split-range installations are common in the condenser make-up water systems in power generating plants.

EXAMPLE: A split-range operation frequently involves a smaller valve of approximately 4" that operates from 3-9 psi, and a second larger 8" valve that operates from 9-25 psi. Typically, the 4" valve provides proper flow and good control, but in the event of a system upset, the 8" valve opens to maintain setpoint level.

F. Some positioners are avilable with optional cams that can be adjusted to modify the flow characteristic of a control valve to linear, equal percentage, quick opening, or square root.

G. In addition to pneumatic positioners, electro-pneumatic positioners are also in common use. These positioners accept a 4-20 mA signal and convert the signal to a pneumatic output signal that can be used by a control valve.

H. In certain critical service where a controller needs to know the exact position of a valve at all times, motion transmitters are used to send the proper signal back to a controller.

I. Motion transmitters typically transmit a pneumatic output signal which is directly proportional to the valve stem position, and are used with all types of indicating and recording equipment.

INFORMATION SHEET

XXI. **Safety in control valve/actuator service**

A. Safety is the number one priority in servicing control valves and actuators because these devices are under pressure.

B. Diaphragm pressure on actuators must always be relieved before any service begins, and the spring pressure on actuators must be relieved to avoid personal injury and the possibility of damaging the actuator.

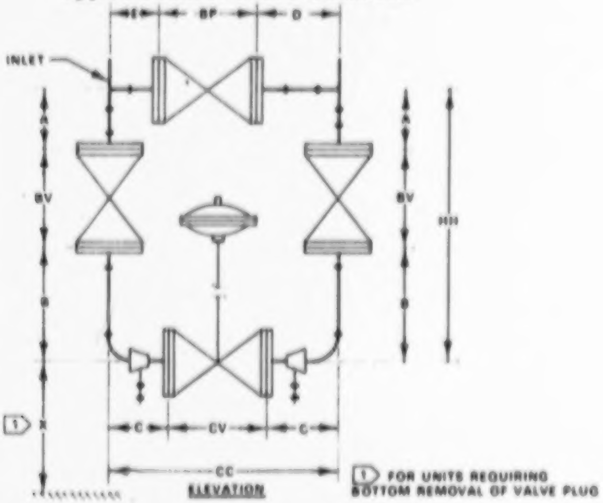
C. Safety is important in removing a control valve from service because the objective is two-fold: to protect the technician(s) and to avoid having to shut the system down.

D. A service bypass which uses blocking valves on each side of a control valve and a throttling valve in a line parallel to the control valve has become the industry standard for control valve service. (Figure 30)

(NOTE: For an in-depth review of the service bypass and how it works, read Handout #1 carefully.)

FIGURE 30

Type I Control Valve Manifold



For low pressure drop applications

Courtesy Fisher Controls Company

E. Almost all facilities have written procedures for valve/actuator service which must be carefully followed.

F. Service literature from manufacturers is vital to properly service any piece of equipment, especially with valves and actuators; always have the right service literature, and follow it to the letter.

INFORMATION SHEET

XXII. **Troubleshooting control valve/actuator subsystems**

A. Final element subsystems are among the easiest parts of a system to troubleshoot because the problems are easy to identify.

B. The control valve/actuator should be evaluated together because they are normally placed into service as a matched pair.

C. Always check supply air with a calibrated gauge to make sure it is at the proper psi; if supply air is okay, then the actuator or valve is at fault and a quick visual inspection may identify the problem.

D. If the actuator doesn't work, it should be replaced, but if it moves smoothly through its full range, then the valve is at fault and should be replaced.

E. NEVER attempt to remove a control valve until you are certain that the supply air line is out of service and that all pressure has been removed.

(CAUTION: Many facilities have strict procedures for removing equipment from service, and a technician should know the procedures and follow them to the letter since unsafe procedures in high pressure service pose a hazard to life and property.)

F. When replacing a valve plug, always use a new valve stem because a new hole will have to be drilled in the stem and an old stem will not hold up in service.

G. When a valve or actuator is repaired or replaced, recalibration of the total final element subsystem is required.

XXIII. **Troubleshooting other final elements**

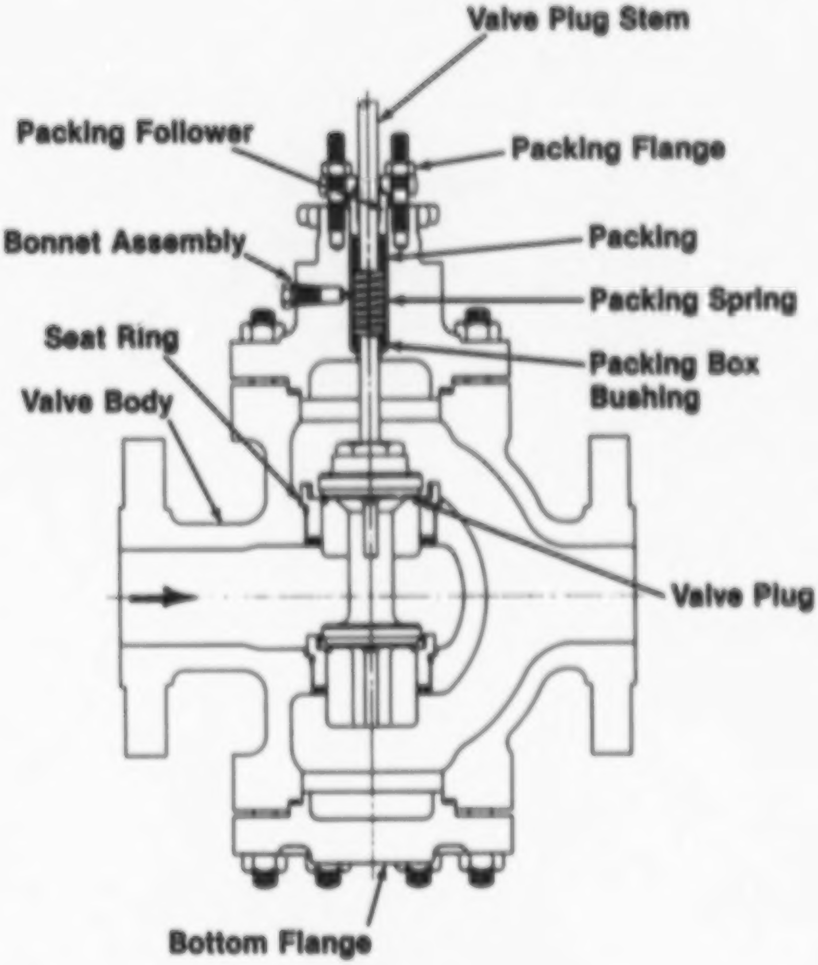
A. Motors used as final elements have to be evaluated with proper meters to check for current draw and proper voltage.

B. Tachometers or strobe lights are used to check motor speeds.

C. Stepper motors should be monitored with an oscilloscope to determine if the proper pulse waveforms are present as specified by the manufacturer.

D. In all troubleshooting activity, it is extremely important to have the manufacturer's data available, and to follow all instructions carefully.

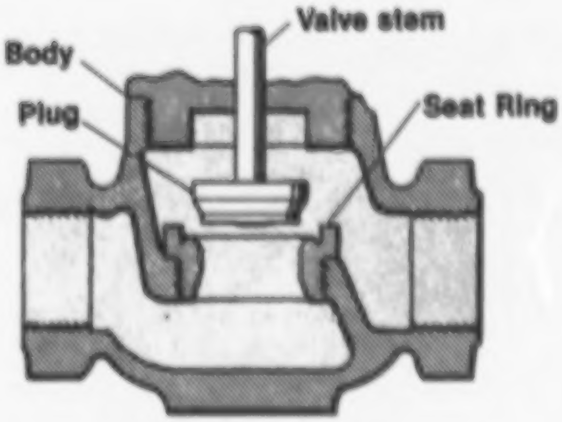
Parts of a Control Valve


Valve Plug Stem
Packing Follower
Packing Flange
Bonnet Assembly
Packing
Packing Spring
Seat Ring
Packing Box Bushing
Valve Body
Valve Plug
Bottom Flange

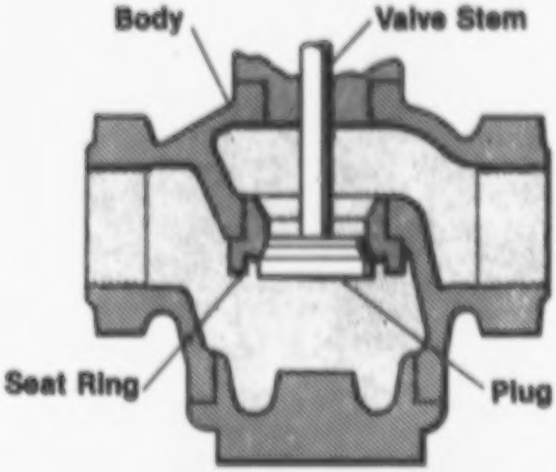
Direct Acting

Courtesy Fisher Controls Company

Basic Control Valve Types


Valve stem
Body
Plug
Seat Ring

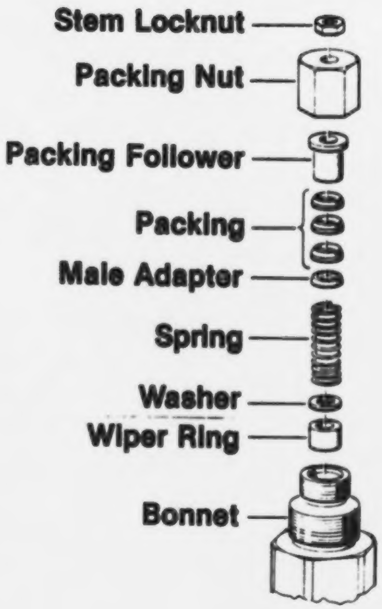
Push-to-Close Valve


Body
Valve Stem
Seat Ring
Plug

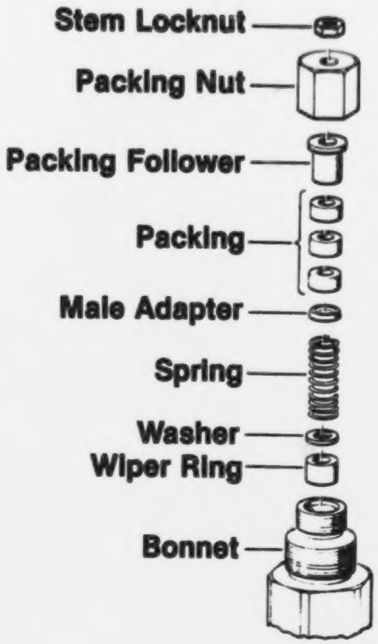
Push-to-Open Valve

Courtesy Taylor Instrument Company

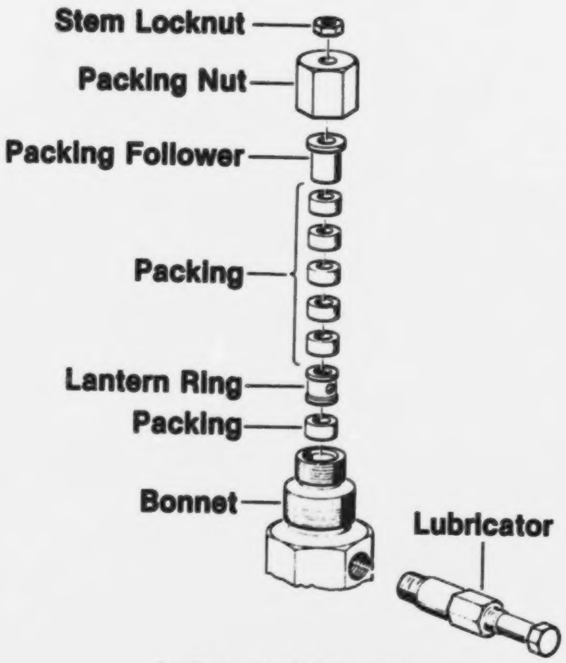
Packing


Stem Locknut
Packing Nut
Packing Follower
Packing
Male Adapter
Spring
Washer
Wiper Ring
Bonnet

Standard Spring-Loaded
TFE V-Ring Packing


Stem Locknut
Packing Nut
Packing Follower
Packing
Male Adapter
Spring
Washer
Wiper Ring
Bonnet

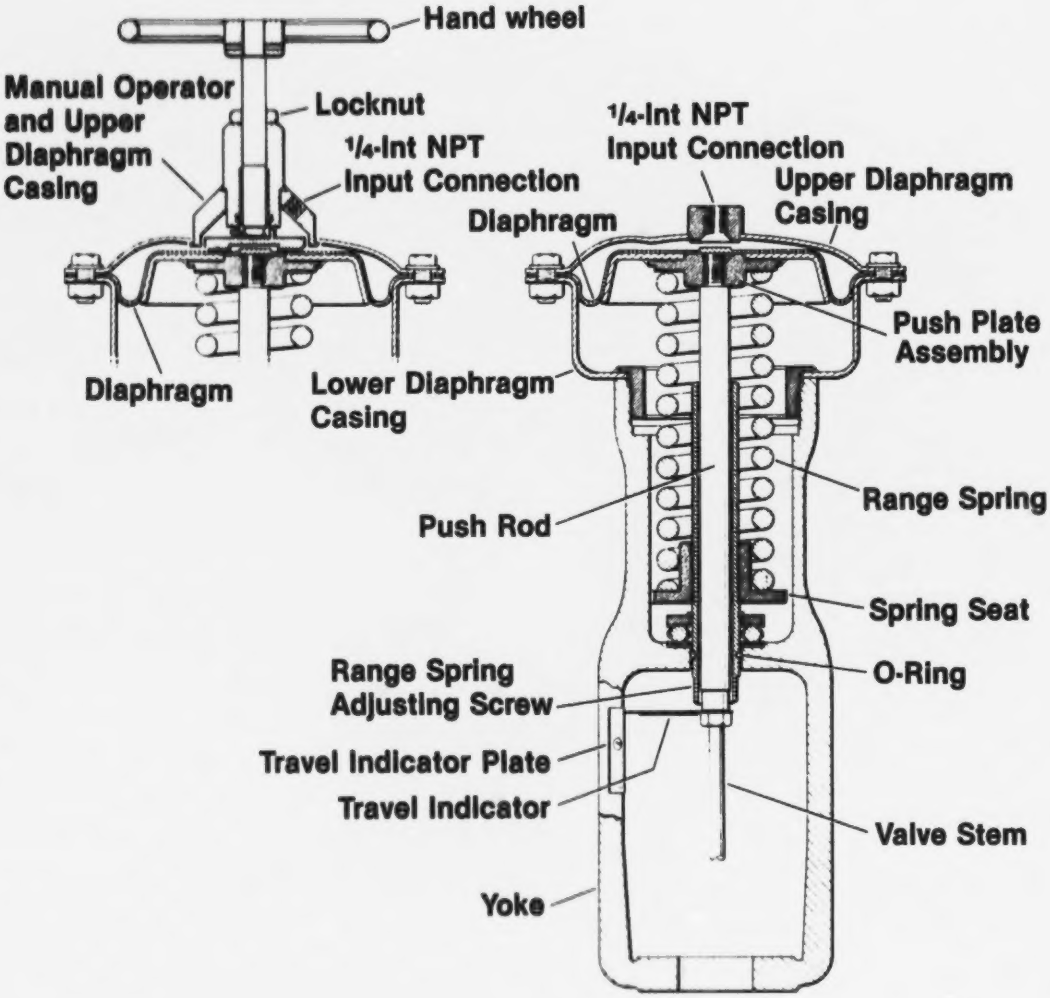
Spring-Loaded
Graphite Packing


Stem Locknut
Packing Nut
Packing Follower
Packing
Lantern Ring
Packing
Bonnet
Lubricator

Lubricated Graphite
Packing with Lubricator

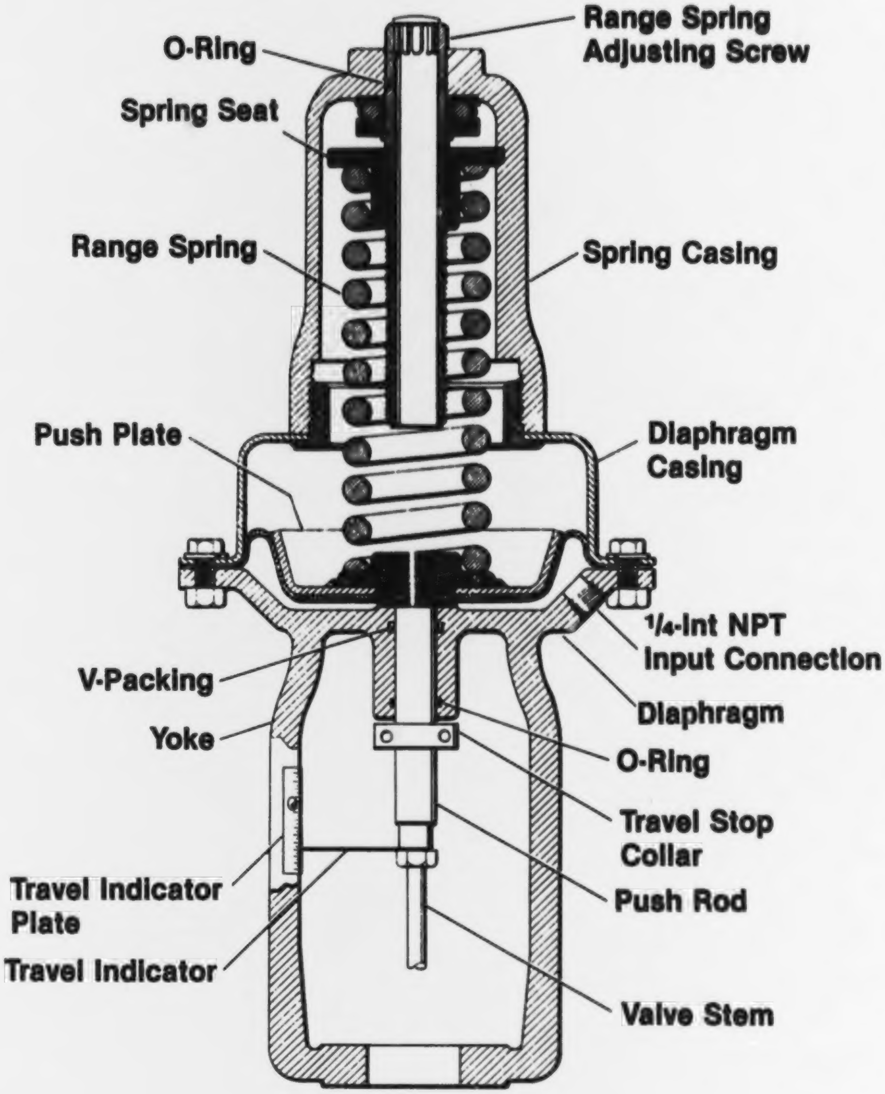
Courtesy Taylor Instrument Company

Air-To-Lower Actuator


Hand wheel
Manual Operator and Upper Diaphragm Casing
Locknut
1/4-Int NPT Input Connection
Diaphragm
Lower Diaphragm Casing
1/4-Int NPT Input Connection
Upper Diaphragm Casing
Diaphragm
Push Plate Assembly
Range Spring
Push Rod
Spring Seat
Range Spring Adjusting Screw
O-Ring
Travel Indicator Plate
Travel Indicator
Valve Stem
Yoke

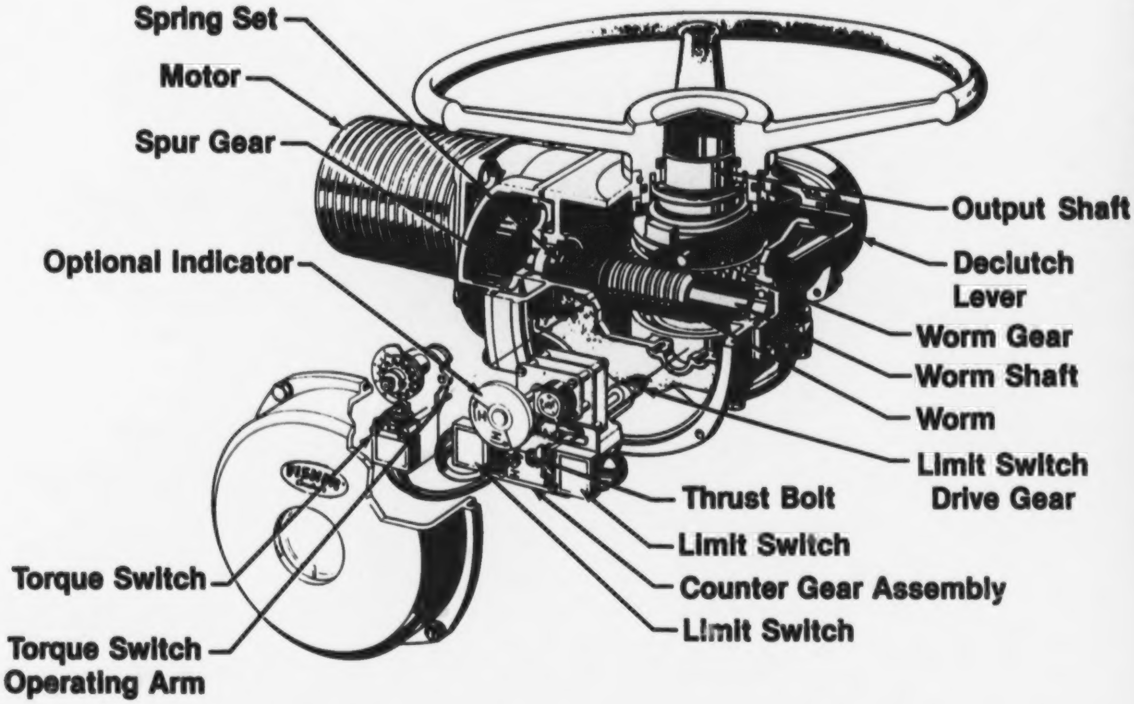
Courtesy Taylor Instrument Company

Air-To-Raise Actuator


O-Ring
Range Spring Adjusting Screw
Spring Seat
Range Spring
Spring Casing
Push Plate
Diaphragm Casing
¼-Int NPT Input Connection
V-Packing
Diaphragm
Yoke
O-Ring
Travel Stop Collar
Push Rod
Travel Indicator Plate
Travel Indicator
Valve Stem

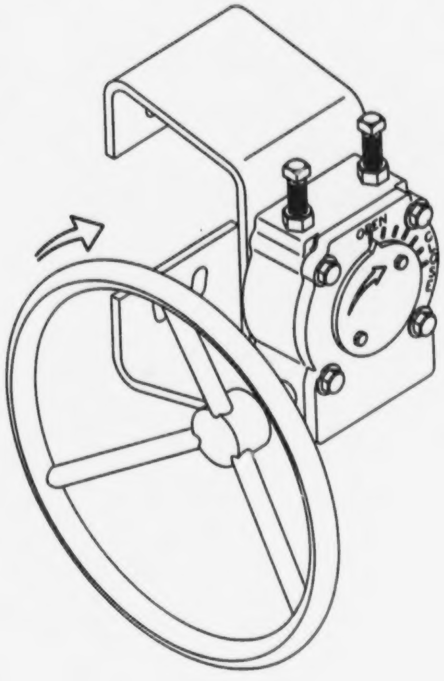
Courtesy Taylor Instrument Company

Electromechanical Actuator

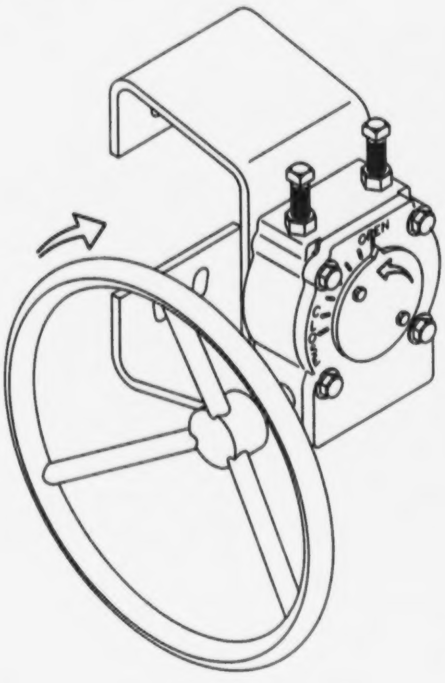

Spring Set
Motor
Spur Gear
Optional Indicator
Torque Switch
Torque Switch Operating Arm
Output Shaft
Declutch Lever
Worm Gear
Worm Shaft
Worm
Limit Switch Drive Gear
Thrust Bolt
Limit Switch
Counter Gear Assembly
Limit Switch
FISHER

Courtesy Fisher Controls Company

Handwheels



Direct Acting



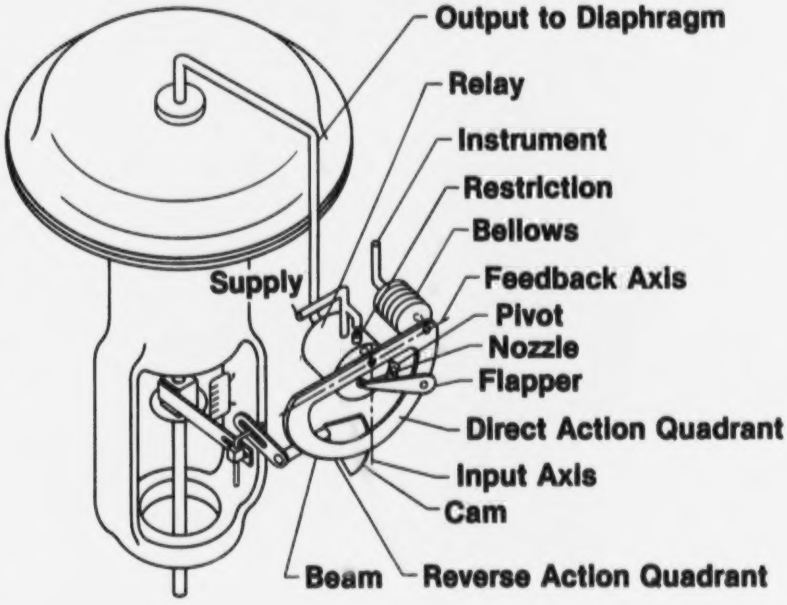
Reverse Acting

Direct Acting: Clockwise rotation of the handwheel produces clockwise rotation of the valve shaft.

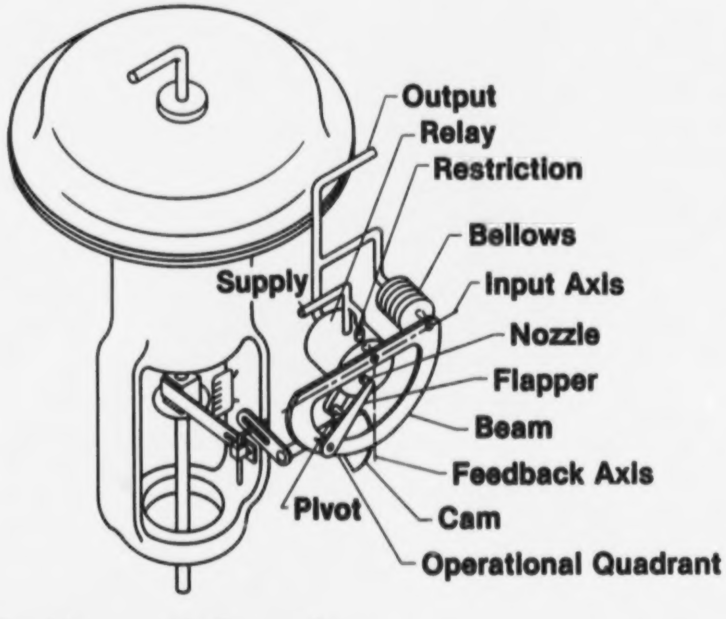
Reverse Acting: Clockwise rotation of the handwheel produces counterclockwise rotation of the valve shaft.

Courtesy Fisher Controls Company

Valve Positioners


Output to Diaphragm
Relay
Instrument
Restriction
Bellows
Supply
Feedback Axis
Pivot
Nozzle
Flapper
Direct Action Quadrant
Input Axis
Cam
Beam
Reverse Action Quadrant

Positioner


Output
Relay
Restriction
Bellows
Supply
Input Axis
Nozzle
Flapper
Beam
Feedback Axis
Pivot
Cam
Operational Quadrant

Positioner with Transmitter

Courtesy Fisher Controls Company

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

HANDOUT #1 — THE CONTROL VALVE SERVICE BYPASS

Purpose

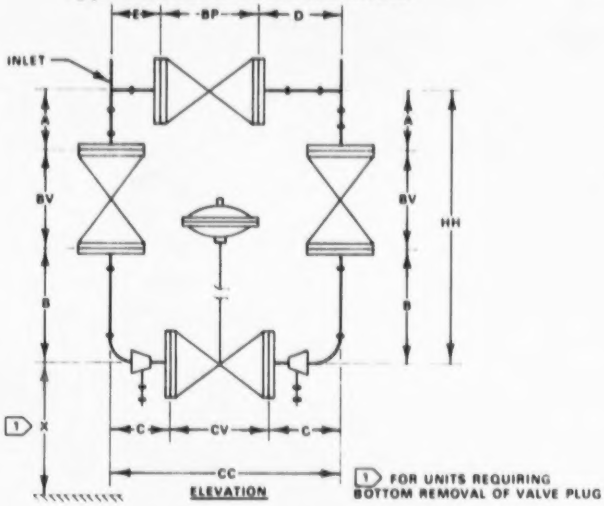
When a control valve needs service or repair, a safe procedure for removing the valve from service is essential for the protection of both personnel and property. The proven procedure for removing a valve from service is the service bypass. The service bypass is designed to permit the safe removal of a valve without shutting a process down. Knowing the configuration of a bypass and how to make the bypass function safely and effectively will provide a technician with valuable experience because when properly accomplished, working the service bypass literally means becoming part of the system.

Structure

The service bypass is constructed in a three-valve configuration with two hand-operated blocking valves in-line on opposite sides of the control valve. The third hand-operated throttling valve is either above or below the control valve, and in-line with the control valve in a parallel bypass line. The bypass line and the three valves are usually no further than an arm span apart. This facilitates service by a single technician. In many cases, the service bypass will also be within visual range of a sight glass or a transmitter output gauge because the technician has to monitor the process as the service bypass is put into operation. (Figure 1)

FIGURE 1

Type I Control Valve Manifold



For low pressure drop applications

Courtesy Fisher Controls Company

HANDOUT # 1

Block and Bleed

Putting the bypass into operation is a procedure of blocking off flow to the control valve, directing flow through the bypass, then bleeding pressure from the control valve so that it can be safely removed from service; that is why it is called block and bleed. Simple? Well, yes and no. It would be easy to block the flow and open the bypass, but it would create a major upset in the flow rate, and that is what we want to avoid. Here is how it is done: Locate the sight glass or transmitter gauge so you can constantly monitor flow or level. Watch the sight glass as you slowly close the upstream blocking valve while at the same time slowly opening the bypass valve. If level or flow begins to fall, close the blocking valve and open the bypass valve a bit faster. If level or flow begin to rise, open the blocking valve and close the bypass valve a bit slower. Keep this up until the upstream blocking valve has completely shut off flow to the control valve and the bypass valve is open far enough to maintain setpoint. In short, as you placed the bypass into service, you were functioning as a system controller. You have had visual feedback from the sight glass where you monitored setpoint, and you managed input to meet setpoint. But is the job finished? No. Now it is time to close the downstream blocking valve. This will leave pressure in the control valve and the control valve line. This pressure can be vented by unscrewing the vent in the valve body, or there may be a small in-line vent valve that can be opened between the control valve and the downstream blocking valve. Once pressure is safely vented from the line, the control valve can be removed from service or safely serviced on site.

The Buddy System

Sight glasses and transmitter gauges are not always close enough to a control valve to visually monitor. In many cases, the gauge is at a remote site, probably a control room. Should that be the case, you will have to find a buddy to monitor level or flow at the remote site while you put the bypass into service. This variation of the procedure obviously requires a couple of walkie talkies. As you put the bypass in service, you are still performing a controller function, but with the buddy system you are getting feedback from a transmitter (the technician in the control room) to monitor setpoint.

Conclusion

The service bypass permits a technician to safely remove a control valve from service without upsetting flow. The secret to putting the service bypass into operation is feedback; that knowledge of setpoint required to make the decision about input requirements. the service bypass literally places a technician in the position of a controller. An experienced technician can put the bypass into operation and never disturb the system. But the most important element of the procedure is that operating pressures can be safely vented from the control valve so it can be removed from service with no danger to personnel or property.

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

JOB SHEET #1 — DISASSEMBLE, INSPECT, AND RESASSEMBLE A GLOBE-TYPE CONTROL VALVE

A. Tools and materials

1. Control valve and actuator as selected by instructor
2. Appropriate service literature
3. Basic hand tools
4. Replacement packing as required
5. Cleaning solvent
6. Clean shop towel
7. Tape measure
8. Safety glasses

B. Routine #1 — Disassembling the valve

The following procedures are adapted from materials published and copyrighted by the Taylor Instrument Company and are reprinted with permission.

1. Put on safety glasses.
2. Refer to Figure 1 that accompanies this job sheet as you complete this routine, and make appropriate entries on the Control Valve Service Data Sheet that is also included.
3. Secure the valve and actuator on a work bench.

   (CAUTION: In actual practice, you must always be CERTAIN that all pressure has been removed from a valve before starting disassembly.)

4. Measure the length of stem thread showing BELOW the stem locknut, and record the dimension here: ____________
5. Loosen the stem locknut.
6. Check service literature at this point to determine if air pressure should be supplied to the actuator in order to move the valve plug off the seat; this has to be done with certain push-to-open valves with air-to-raise actuator, and push-to-open valves with air-to-lower actuators.

JOB SHEET #1

7. Shut off pressure to the actuator, if required, and disconnect supply air.

8. Loosen the valve mounting nut, and double check to make sure that all pressure has been relieved from the actuator.

9. Unscrew the mounting nut.

10. Unscrew the valve stem and plug assembly from the push rod by rotating the actuator.

    (NOTE: If you have to use pliers to hold the valve stem, be sure the pliers grip the stem near the threads to avoid damaging the lower portion of the stem.)

11. Lift the actuator off the valve body.

12. Remove the stem locknut and loosen the packing nut.

13. Unscrew the bonnet from the valve body.

    (CAUTION: If it is a push-to-close valve, the valve plug and stem will probably come out with the bonnet.)

14. Unscrew the packing nut and remove the packing follower from the bonnet.

15. Remove valve plug and stem assembly.

    (CAUTION: On push-to-open valves, remove the bottom plug and pull the valve plug and stem assembly from the bottom of the valve; this may damage tha packing, and if so, the packing should be replaced.)

16. Inspect the valve plug and stem assembly for scratches or nicks that would indicate they have to be replaced.

17. Inspect the seat-ring for scratches or nicks that would indicate it has to be replaced.

    ☐ Have your instructor check your work.

C. Routine #2 — Reassembling the valve

(NOTE: Your instructor may direct you to replace packing or to replace the ring-seat if these items are damaged or worn. These procedures are covered in other job sheets that accompany this unit.)

1. Put on safety glasses.

2. Install the stem locknut and travel indicator on the valve stem.

JOB SHEET #1

3. Mount the actuator on the valve body, and install the valve mounting nut over the stem assembly as the stem passes the boss.

   (NOTE: Continue to refer to Figure 1 that accompanies this job sheet as you complete this procedure.)

4. Refer to the dimension recorded in Step 4 of Routine #1 and write that dimension here: ____________

5. Use your recorded dimension as a reference for the following part of reassembly, being careful not to rotate the valve plug on the seat-ring as you reassemble the valve.

6. Screw the valve plug and stem assembly into the push rod according to the following:

   a. If it is a push-to-close valve with air-to-lower actuator, screw the stem assembly into the push rod by turning the actuator until the valve plug is about 1/4" above the seat valve, and then tighten the valve mounting nut.

   b. If it is a push-to-close valve with air-to-raise actuator, move the valve plug to its fully closed position, and screw the stem assembly into the push rod by turning the actuator until a gap of about 1/8" shows between the bonnet and the actuator. Next, apply pressure to the actuator until the 1/8" gap closes, tighten the valve mounting nut, and remove the pressure.

   c. If it is a push-to-open valve with air-to-raise actuator, move the valve plug to its fully open position. Next, screw the stem assembly into the push rod by turning the actuator until the bonnet is tight to the actuator. Then tighten the valve mounting nut.

   d. If it is a push-to-open valve with air-to-lower actuator, place a mark on the push rod next to the actuator, and move the valve plug to its fully closed position. Screw the stem assembly into the push rod by turning the actuator until the push rod is pulled down 3/16". If necessary, grip the valve stem with pliers to keep the valve plug from turning on the seat.

7. Align the travel indicator with the scale and tighten the stem locknut.

   ☐ Have your instructor check your work.

   (NOTE: At this point, your instructor may ask you to adjust the valve plug travel which should be accomplished when a valve is placed back in service. This procedure is covered in Job Sheet #2.)

8. Clean up area and return tools and materials to proper storage.

JOB SHEET #1

Control Valve Service Data

Date__________ Technician____________________ Title_______________

Time on ☐ Time off ☐ Field ☐ Bench ☐

Manufacturer ____________________ Serial # _______________

Model ____________________ Size _______________

Body material ____________________ Trim material _______________

Plug type ____________________ Plug size _______________

Packing type ____________________________________

Lubricant ____________________________________

End connections: ☐ Screwed ☐ Flanged ☐ Welded

Location ____________________________________

(Loop # and P&ID reference if needed)

Reported problem

Corrective action

Actuator

Manufacturer ____________________ Serial # _______________

Model ____________________ Size _______________

Reported problem

Corrective action

JOB SHEET #1

Valve Positioner

Manufacturer ______________________ Serial # ______________________

Model ______________________ Size ______________________

Reported problem

Corrective action

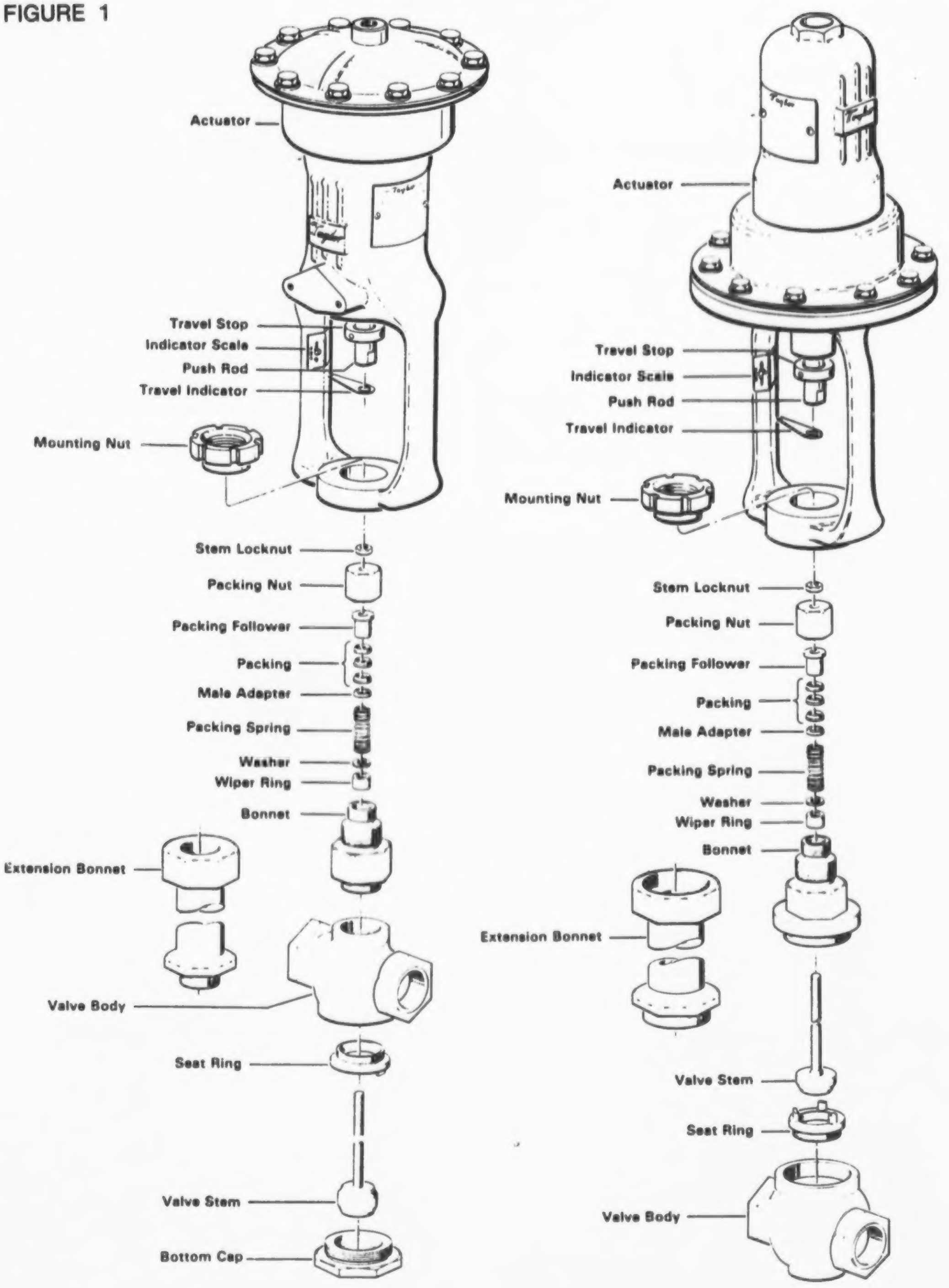
Upstream: ______________________

Downstream: ______________________

Other service notes and observations: ______________________

JOB SHEET #1

FIGURE 1


Actuator
Travel Stop
Indicator Scale
Push Rod
Travel Indicator
Mounting Nut
Stem Locknut
Packing Nut
Packing Follower
Packing
Male Adapter
Packing Spring
Washer
Wiper Ring
Bonnet
Extension Bonnet
Valve Body
Seat Ring
Valve Stem
Bottom Cap
Actuator
Travel Stop
Indicator Scale
Push Rod
Travel Indicator
Mounting Nut
Stem Locknut
Packing Nut
Packing Follower
Packing
Male Adapter
Packing Spring
Washer
Wiper Ring
Bonnet
Extension Bonnet
Valve Stem
Seat Ring
Valve Body

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ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

JOB SHEET #2 — ADJUST VALVE PLUG TRAVEL ON AN ACTUATOR

A. Tools and materials

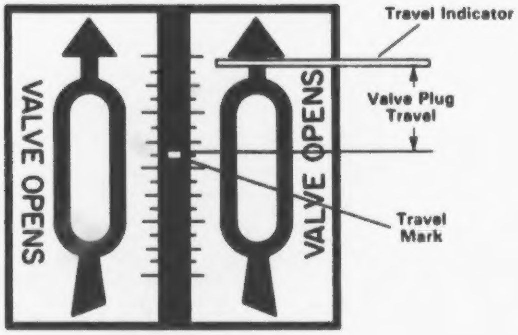
1. Actuator and globe valve as selected by instructor (Taylor Hi-Flow™ valve with Lin-E-Aire© actuator or equivalent)
2. Appropriate service literature
3. Basic hand tools
4. Tape measure
5. Pencil or pen
6. Safety glasses

B. Routine #1 — Disassembling the valve

The following procedures are adapted from materials published and copyrighted by the Taylor Instrument Company and are reprinted with permission.

1. Put on safety glasses.
2. Make sure the valve/actuator are free of pressure.
3. Secure the valve/actuator on a work bench.
4. Apply enough air pressure slowly to the actuator to fully close the valve.
5. Note the location of the travel indicator. (Figure 1)

FIGURE 1



Courtesy Taylor Instrument Company

JOB SHEET #2

6. Determine whether the travel indicator is at the travel mark on the plat that indicates the valve is closed; if it is not, measure the distance between the indicator and the travel mark and record that dimension here: ____________

7. Do not make any adjustments when the valve plug is on its seat.

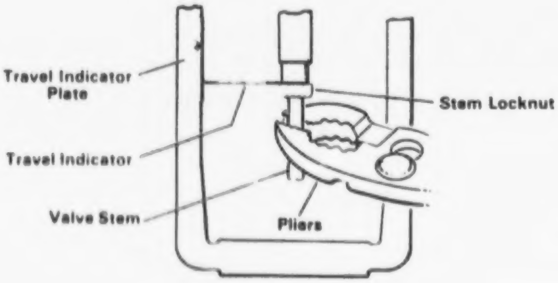
8. Vent all pressure from the actuator.

9. Loosen the stem locknut. (Figure 2)

10. Use pliers to grip the valve stem near the threads, and turn the stem enough to move the valve plug the distance measured in step 6. (Figure 1)

    (CAUTION: Handle the pliers with care and keep them up close to the threads to avoid scratching the valve stem.)

    FIGURE 2



Courtesy Taylor Instrument Company

11. Make sure the travel indicator is pointing properly toward the travel indicator plate.

12. Tighten the valve stem locknut.

    ☐ Have your instructor check your work.

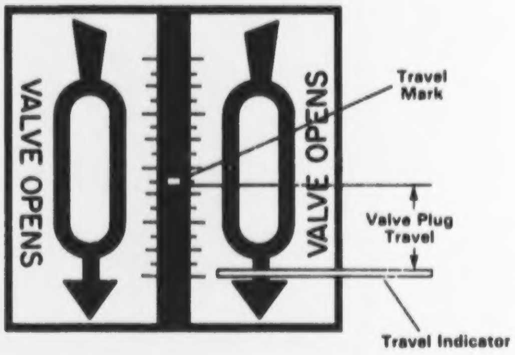
C. Routine #2 — Adjusting valve plug travel with air-to-raise actuator

1. Put on safety glasses
2. Make sure the valve/actuator are free of pressure.
3. Secure the valve actuator on a work bench.
4. Apply enough air pressure slowly to the actuator to fully open the valve.

JOB SHEET #2

5. Note the location of the travel indicator. (Figure 3)

FIGURE 3



Courtesy Taylor Instrument Company

6. Determine whether the travel indicator is at the travel mark on the plate that indicates the valve is open, and if it is not, measure the distance between the indicator and the travel mark and record that dimension here: ____________

7. Do not make any adjustments if the valve plug demonstrates proper travel; continue if adjustments are required.

8. Loosen the stem locknut, use pliers to grip the valve stem near the threads, and turn the stem enough to move the valve plug the distance measured in Step 6. (Refer to Figure 2)

9. Vent all pressure from the actuator.

10. Repeat the procedure until the travel indicator is at the appropriate travel mark when valve is fully open.

    ☐ Have your instructor check your work.

11. Clean area and return tools and materials to proper storage.

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

JOB SHEET #3 — ADJUST RANGE ON AN ACTUATOR

A. Tools and materials

1. Air-to-lower actuator (Taylor Hi-Flow™ valve with Lin-E-Aire© actuator or equivalent)
2. Air-to-raise actuator (Taylor Hi-Flow™ valve with Lin-E-Aire© actuator or equivalent)
3. Basic hand tools
4. Shut off valve
5. Pressure regulator
6. Pressure gauge (accurate to ±0.1 psi)
7. Tubing and fittings as required
8. Safety glasses

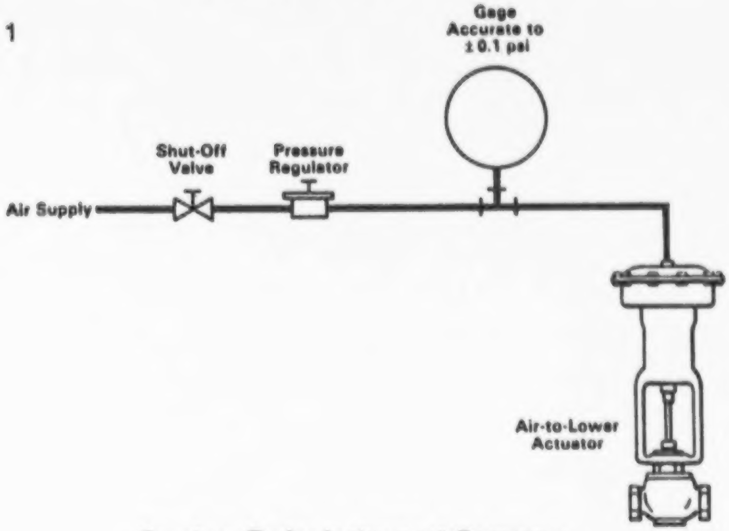
B. Routine #1 — Adjusting actuator range on an air-to-lower actuator with a push-to-close valve

The following procedures and illustrations are adapted from materials published and copyrighted by the Taylor Instrument Company and are reprinted with permission.

1. Put on safety glasses.
2. Secure the actuator and valve on a test bench.
3. Hook up shut-off valve, pressure regulator, pressure gauge, and actuator as illustrated. (Figure 1)

JOB SHEET #3

FIGURE 1


Gage Accurate to ± 0.1 psi
Shut-Off Valve
Pressure Regulator
Air Supply
Air-to-Lower Actuator

Courtesy Taylor Instrument Company

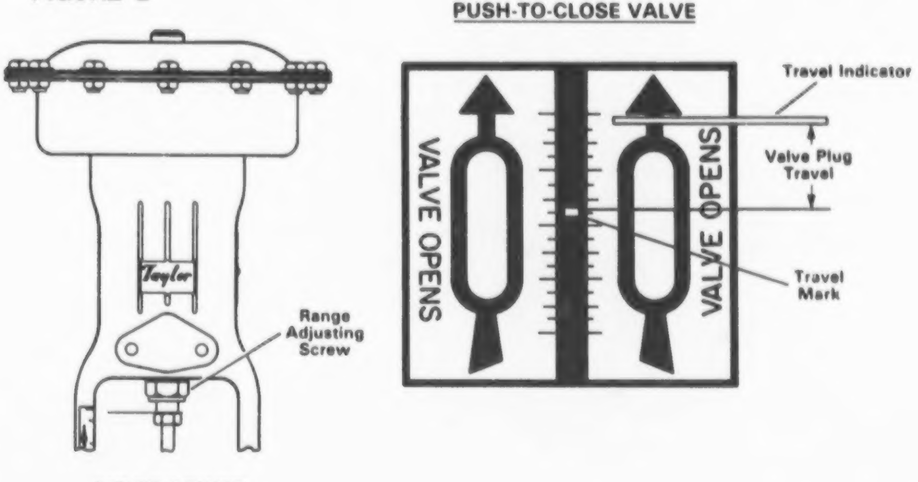
4. Turn on supply air and slowly increase input pressure until the valve stem just begins to move.

5. Feel the valve stem so you can accurately detect when it begins to move.

6. Note the input pressure at which the valve stem starts to move: ____________

7. Compare the input pressure with the lower input pressure range on the actuator data plate, and if the two pressures are not the same, the range adjusting screw must be adjusted. (Figure 2)

FIGURE 2


PUSH-TO-CLOSE VALVE
Taylor
Range Adjusting Screw
VALVE OPENS
VALVE OPENS
Travel Indicator
Valve Plug Travel
Travel Mark

AIR-TO-LOWER

Courtesy Taylor Instrument Company

JOB SHEET #3

8. Adjust the range according to the following:
    a. If pressure is high, turn the adjusting screw counterclockwise as viewed from the valve top.
    b. If pressure is low, turn the adjusting screw clockwise as viewed from the valve top.

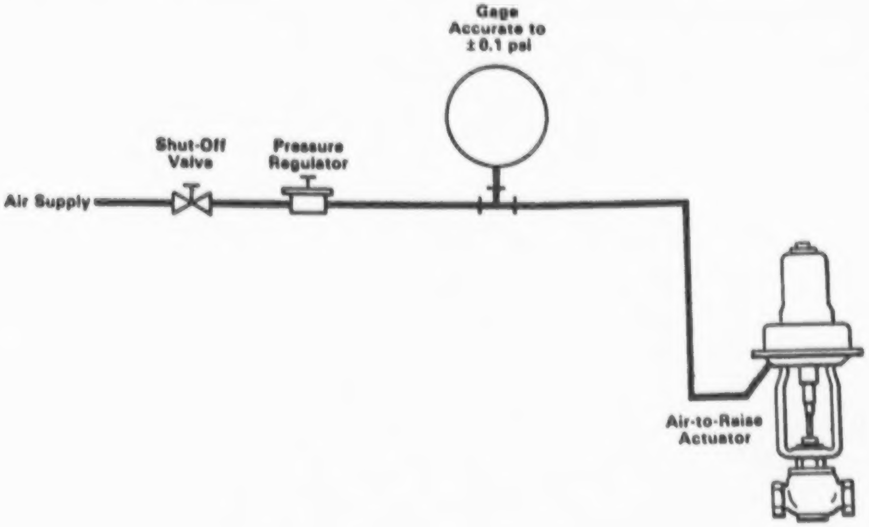
       (NOTE: Make adjustments in relation to how high or low the pressure reading is, and remember that slight adjustments are usually in order.)
9. Release the input pressure and retest.
10. Repeat the adjustment procedure as required until the valve stem moves at the lower range value.

    ☐ Have your instructor check your work.

C. Routine #2 — Adjusting actuator range on an air-to-raise actuator with a push-to-open valve

1. Put on safety glasses
2. Secure the actuator and valve on a test bench.
3. Prepare test hookup as illustrated. (Figure 3)

FIGURE 3


Gage
Accurate to
± 0.1 psi
Shut-Off
Valve
Pressure
Regulator
Air Supply
Air-to-Raise
Actuator

Courtesy Taylor Instrument Company

JOB SHEET #3

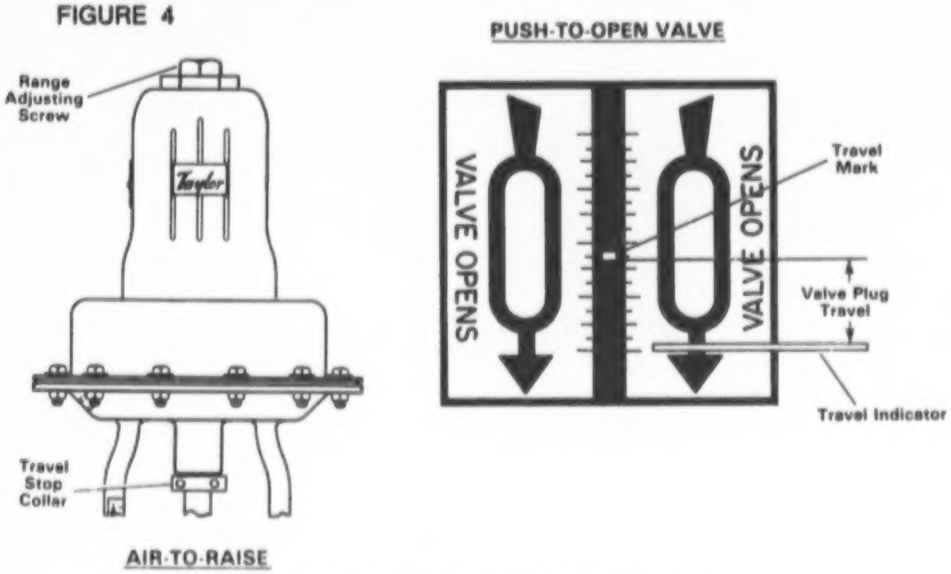
4. Turn on air supply and slowly increase input pressure until the valve stem just begins to move.

5. Feel the valve stem so you can accurately detect when movement begins.

6. Note the input pressure at which valve stem starts to move: ____________

7. Compare the input pressure with the lower input pressure range on the actuator data plate, and if the two pressures are not the same, the range adjusting screw must be adjusted. (Figure 4)

FIGURE 4



PUSH-TO-OPEN VALVE

AIR-TO-RAISE

Range Adjusting Screw
Taylor
Travel Stop Collar
VALVE OPENS
VALVE OPENS
Travel Mark
Valve Plug Travel
Travel Indicator

Courtesy Taylor Instrument Company

8. Adjust the range according to the following:

    a. If pressure is high, turn the adjusting screw counterclockwise as viewed from the top of the valve.

    b. If pressure is low, turn the adjusting screw clockwise as viewed from the top of the valve.

9. Release the input pressure and retest.

10. Repeat the adjustment procedure as required until the valve stem moves at the lower range value.

    ☐ Have your instructor check your work.

11. Clean up area and return tools and materials to proper storage.

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

JOB SHEET #4 — REPLACE THE DIAPHRAGM ON AN AIR-TO-LOWER ACTUATOR

A. Tools and materials

1. Valve/actuator as sected by instructor (Taylor Hi-Flow™ valve with Lin-E-Aire© actuator or equivalent)
2. Appropriate service literature
3. Molded diaphragm replacement as required
4. Basic hand tools
5. Safety glasses

B. Procedure

The following procedures and illustrations are adapted from materials published and copyrighted by the Taylor Instrument Company and are reprinted with permission.

1. Put on safety glasses.
2. Bypass the control valve in the pipe line with an approved safety procedure.
3. Shut off pressure to the actuator and disconnect the air supply.

   (NOTE: Refer to Figure 1 that accompanies this job sheet as you continue this procedure.)

4. Turn the range spring adjustment screw counterclockwise to relieve all spring compression.

   (CAUTION: If all spring compression is not relieved, serious injury can result when removing the upper diaphragm casing.)

5. Loosen and remove all diaphragm casing mounting screws, nuts, and washers, and save them for reassembly.
6. Lift off the upper diaphragm casing from the actuator assembly.
7. Remove and discard the old diaphragm.
8. Install new diaphragm and upper diaphragm casing on actuator assembly.

JOB SHEET #4

9. Fasten with bolts, nuts, and washers previously removed, and tighten mounting screws in an a criss-cross pattern to assure an even, tight fit.

10. Reconnect pipe or tubing to the pressure connection in the upper diaphragm casing.

    ☐ Have your instructor check your work.

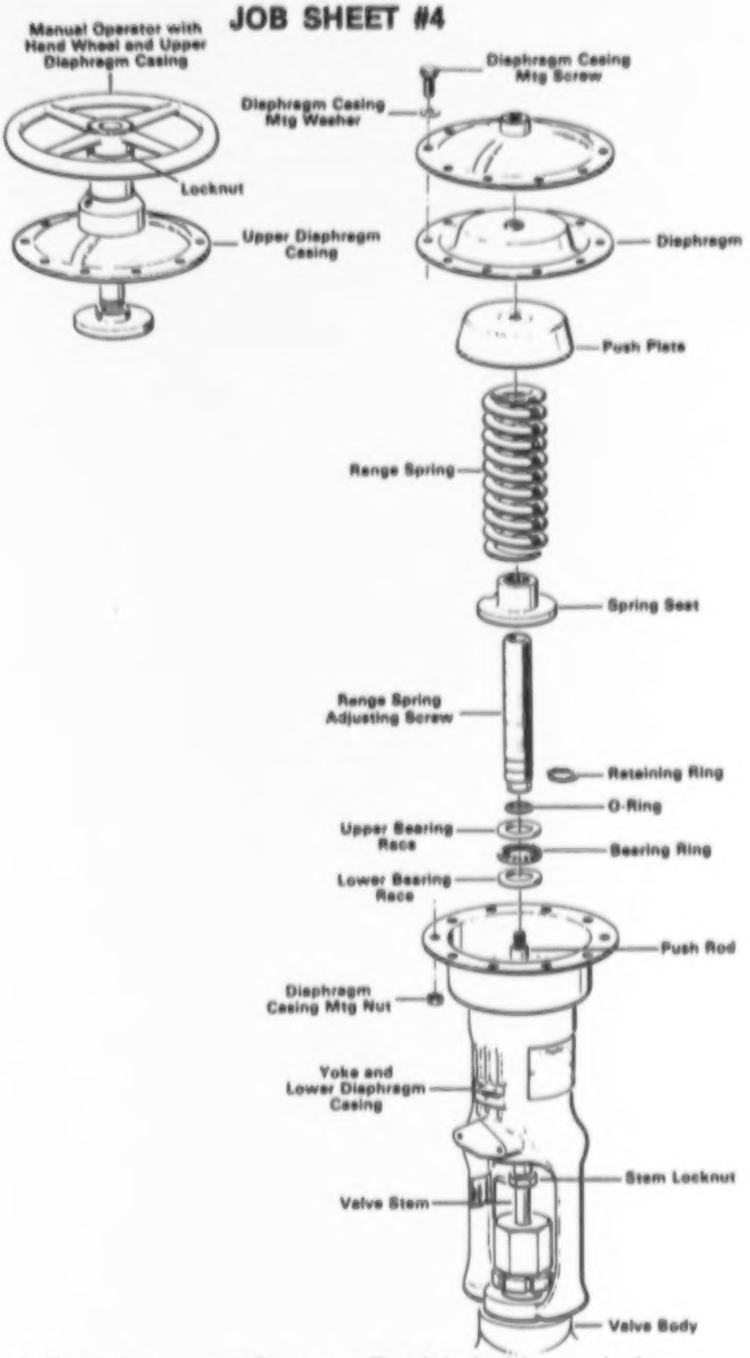
11. Readjust actuator travel as outlined in Job Sheet #2.

    ☐ Have your instructor check your work.

    (NOTE: This procedure is the same as that used with a manually operated actuator, except that the first step in that service would be to turn the handwheel counterclockwise to relieve all pressure on the diaphragm, and then be sure to relieve range spring compression.)

JOB SHEET #4

FIGURE 1


Manual Operator with Hand Wheel and Upper Diaphragm Casing
Locknut
Upper Diaphragm Casing
Diaphragm Casing Mtg Screw
Diaphragm Casing Mtg Washer
Diaphragm
Push Plate
Range Spring
Spring Seat
Range Spring Adjusting Screw
Retaining Ring
O-Ring
Upper Bearing Race
Bearing Ring
Lower Bearing Race
Push Rod
Diaphragm Casing Mtg Nut
Yoke and Lower Diaphragm Casing
Stem Locknut
Valve Stem
Valve Body

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ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

JOB SHEET #5 — REPLACE THE SEAT-RING ON A GLOBE-TYPE CONTROL VALVE

A. Tools and materials

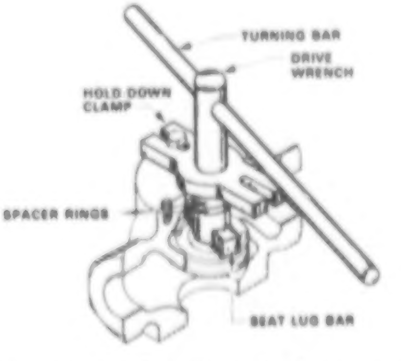
1. Globe-type control valve as selected by instructor
2. Appropriate service literature
3. Basic hand tools and pipe compound
4. Seat ring puller (Fisher Controls or equivalent)
5. Replacement threaded seat-ring(s) as required
6. Cleaning solvent and clean shop cloth
7. Safety glasses

B. Procedure

The following procedure and illustration have been adapted from materials published and copyrighted by the Fisher Controls Company and are reprinted with permission.

1. Put on safety glasses.
2. Follow all safety procedures required if the control valve must first be removed from service.
3. Secure the valve on a work bench.
4. Examine Figure 1 to acquaint yourself with the parts of the seat-ring puller. (Figure 1)

FIGURE 1



Courtesy Fisher Controls Company

JOB SHEET #5

5. Place the proper size seat lug bar across the seat ring so that the bar contacts the seat lugs as shown in Figure 1.

6. Insert the drive wrench and place enough spacer rings over the wrench so that the hold-down clamp will rest about 1/4" above the body flange.

7. Slip hold-down clamp onto the drive wrench, and secure the clamp to the body with two cap screws from the bonnet, but do not tighten the cap screws.

8. Insert the turning bar through the top of the drive wrench, and turn the bar counterclockwise to unscrew the seat-ring.

   (NOTE: Seat-rings often stick so you may have to slip a 3 to 5-foot length of pipe over the turning bar, apply pressure on one end of the bar, and hit the pipe with a quick, heavy hammer blow to break the seat-ring loose.)

9. Make sure the seat-ring is completely loose, alternately unscrew the cap screws on the hold-down clamp, and unscrew the seat-ring by hand the rest of the way.

10. Clean the threads in the valve body port.

    (NOTE: If you are working with a double-port valve body, there will be two seat-rings to remove. When you replace the rings, replace the small ring first, being sure to check the service literature for special procedures for the specific valve you are working with.)

11. Apply pipe compound to the male threads of the new seat-ring.

12. Screw the new seat-ring into the valve body.

13. Reinstall the seat-ring puller, and reverse the removal procedure to tighten the new seat-ring in place.

14. Clean any excess pipe compound from the seat-ring after it is in place.

    ☐ Have your instructor check your work.

15. Reassemble the valve.

16. Clean up area and return tools and materials to proper storage.

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

PRACTICAL TEST #1
JOB SHEET #1 — DISASSEMBLE, INSPECT, AND REASSEMBLE A GLOBE-TYPE CONTROL VALVE

Student's name ______________________________ **Date** ____________

Evaluator's name ______________________________ **Attempt no.** ______

> Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Prepared valve safely for disassembly.	1.	☐	☐
2. Measured stem thread accurately.	2.	☐	☐
3. Disassembled valve.	3.	☐	☐
4. Inspected valve components.	4.	☐	☐
5. Reassembled valve properly.	5.	☐	☐
6. Aligned travel indicator properly.	6.	☐	☐
7. Returned equipment to proper storage.	7.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #1 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Tools and Equipment	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Materials	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Procedure	Carefully followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ____________________

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

PRACTICAL TEST #2
JOB SHEET #2 — ADJUST VALVE PLUG TRAVEL ON AN ACTUATOR

Student's name ______________________________ **Date** ____________

Evaluator's name ______________________________ **Attempt no.** ______

Student instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Prepared valve safely.	1.	☐	☐
2. Adjusted valve plug travel properly.	2.	☐	☐
3. Aligned travel indicator and plate.	3.	☐	☐
4. Adjusted travel on air-to-raise actuator.	4.	☐	☐
5. Secured valve and actuator(s).	5.	☐	☐
6. Returned equipment to proper storage.	6.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #2 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Tools and Equipment	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Materials	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Procedure	Carefully followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ____

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

PRACTICAL TEST #3
JOB SHEET #3 — ADJUST RANGE ON AN ACTUATOR

Student's name ______________________________ **Date** ____________

Evaluator's name ______________________________ **Attempt no.** ______

Student instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Prepared air-to-lower actuator and push-to-close valve properly.	1.	☐	☐
2. Made proper range adjustment.	2.	☐	☐
3. Prepared air-to-raise actuator and push-to-close valve.	3.	☐	☐
4. Made proper range adjustment.	4.	☐	☐
5. Returned equipment to proper storage.	5.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #3 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Tools and Equipment	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Materials	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Procedure	Carefully followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ____

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

PRACTICAL TEST #4
JOB SHEET #4 — REPLACE THE DISPHRAGM ON AN AIR-TO-LOWER ACTUATOR

Student's name ______________________________ **Date** ____________

Evaluator's name ______________________________ **Attempt no.** ______

Student instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:			YES	NO
1.	Safely bypassed control valve.	1.	☐	☐
2.	Safely relieved all spring pressure.	2.	☐	☐
3.	Removed diaphragm casing and old diaphragm.	3.	☐	☐
4.	Installed new diaphragm properly.	4.	☐	☐
5.	Tightened diaphragm casing with proper criss-cross pattern.	5.	☐	☐
6.	Reconnected pressure connections.	6.	☐	☐
7.	Readjusted actuator travel.	7.	☐	☐
8.	Returned equipment to proper storage.	8.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #4 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Tools and Equipment	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Materials	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Procedure	Carefully followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ____

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

PRACTICAL TEST #5
JOB SHEET #5 — REPLACE THE SEAT-RING ON A GLOBE-TYPE CONTROL VALVE

Student's name ______________________________ **Date** ____________

Evaluator's name ______________________________ **Attempt no.** ______

> Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Prepared valve safely.	1.	☐	☐
2. Used seat-ring puller properly.	2.	☐	☐
3. Cleaned treads in valve body port.	3.	☐	☐
4. Installed new seat ring properly.	4.	☐	☐
5. Tightened new seat ring properly.	5.	☐	☐
6. Cleaned seat ring.	6.	☐	☐
7. Reassembled valve properly.	7.	☐	☐
8. Returned equipment to proper storage.	8.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #5 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Tools and Equipment	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Materials	Properly selected and used 4	Acceptably selected and used 3	Poorly selected and used 2	Improperly selected and used 1
Procedure	Carefully followed 4	Acceptably followed 3	Poorly followed 2	Improperly followed 1
Safety	Carefully observed 4	Acceptably observed 3	Poorly observed 2	Improperly observed 1

EVALUATOR'S COMMENTS: ____

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

TEST

NAME ______________________________ SCORE ______________

1. Match the terms on the right with their correct definitions.

______a. That part of a process system which responds to controller output in order to maintain a controlled variable at setpoint

______b. A valve designed for service as a final element

______c. That part of a valve through which a valve plug stem moves, which contains a means for sealing against leakage along the stem, and which provides a means for attaching an actuator

______d. That part of a bonnet assembly used to seal against leakage around the valve plug stem

______e. A movable part which provides a variable restriction in a valve port

______f. A rod extending through a valve bonnet assembly to permit positioning of the valve plug

______g. That portion of a valve plug which aligns plug movement in either a seat-ring, bonnet, bottom flange, or any two of these

______h. The internal parts of a valve which come in contact with flowing fluid

______i. A control valve designed to operate at one of two positions, fully open or fully closed

______j. A control valve designed to operate between the limits of fully open or fully closed

______k. A phenomena that occurs when fluid pressure rises above vapor pressure of a fluid, causing entrained bubbles to collapse and damage valve components

1. On/Off valve
2. Valve plug
3. Flashing
4. Control valve
5. Cavitation
6. Packing box
7. Noise attenuation
8. Final element
9. Throttling valve
10. Valve plug stem
11. Valve plug guide
12. Bonnet assembly
13. Trim

TEST

______l. A phenomena that occurs when fluid pressure drops below vapor pressure of a fluid and produces bubbles which remain in the fluid and damage valve components

______m. The modification or addition of valve trim to control hydrodynamic noise resulting from liquid flow or aerodynamic noise resulting from the turbulent flow of gas

2. Match parts of a control valve with their functions.

______a. A housing with inlet and outlet flow connections that serves also to house internal parts, and to which external parts are attached

______b. An assembly that includes the part through which the valve plug stem moves, and a means for protecting the stem from leaking

______c. A part which closes a valve body opening opposite the bonnet assembly

______d. A movable part that provides a variable restriction in a plug

______e. A rod extending through the bonnet assembly to permit positioning of the valve plug

______f. That part of a valve plug which aligns its movement with a seat ring, bonnet, bottom flange, or any two of these

______g. A piece inserted into a valve body to form a valve body port

______h. A structure by which the diaphragm or cylinder assembly is supported rigidly on the bonnet assembly

______i. That area inside the bonnet into which the packing and packing springs are placed

______j. Material inserted around a valve plug stem to prevent the stem from leaking

______k. A spring situated below the packing so that it exerts pressure upward on the packing

1. Valve plug
2. Seat ring
3. Packing spring
4. Packing flange
5. Valve body
6. Packing
7. Bonnet assembly
8. Packing box
9. Packing follower
10. Bottom flange
11. Packing box bushing
12. Valve plug stem
13. Valve plug guide
14. Yoke

TEST

______l. A device that holds the packing spring and helps guide the valve plug stem through the bonnet assembly

______m. A bushing-like material placed between the packing and the packing flange to help assure a tight packing seal

______n. A flange that fits on top of the bonnet and is secured with studs and nuts to seal the top over the packing follower

3. Complete statements concerning control valve characteristics by circling the material that best completes each statement.

   a. Control valves are also classified according to how they open and close in response to actuator action:

      1) A push-down-to-close valve closes as the actuator moves the valve stem plug down on the (**seat ring, stem**) to close the valve.

      2) A push-down-to-close control valve is also called a (**direct acting valve, high-speed valve**).

      3) A push-down-to-open valve opens as the actuator moves the (**cage, valve stem plug**) away from the seat ring to open the valve.

      4) A push-down-to-open control valve is also called a (**reverse acting valve, throttling valve**).

   b. Another control valve classification concerns the position of the valve port in the event of actuator power failure:

      1) In a fail-closed valve, the port remains (**closed, open**) when actuator power fails.

      2) In a fail-open valve, the port remains (**open, closed**) when actuator power fails.

      3) In a (**fail-safe valve, multi-use valve**), the valve plug will fully close the port, fully open the port, or remain in a fixed position according to actuator design as dictated by the system.

      4) If a hazardous condition would result when input is too high, the valve should fail (**low, high**).

      5) If a hazardous condition would result when input is too low, the valve should fail (**high, low**).

TEST

c. A control valve has a flow arrow on the body, and the valve should be installed so that the flow is (**against the direction, in the direction of**) the arrow.

d. Some control valves without flow arrows will have (**"IN" and "OUT", "ON" and "OFF"**) stamped on the flanges.

e. Flow leading into a control valve is said to be (**"downstream, "upstream,"**) and flow going away from the control valve is said to be (**"downstream", "upstream"**).

f. Control valves generally are on/off valves or (**"throttling", push-down-to-close**) valves that control flow in between the limits of fully open or fully closed.

4. Solve problems concerning flow characteristics of control valves by selecting the correct answer.

a. Valves with what characteristics are often used for liquid level control, equal percentage flow or linear flow?

Answer: ______________________________

b. Valves with what flow characteristics are often used on pressure control applications or where highly varying pressure drops can be expected, equal percentage flow or quick opening flow?

Answer: ______________________________

c. Valves with what flow characteristics are often used in applications where high volume flow rate must be established quickly, linear flow or quick opening flow?

Answer: ______________________________

5. Select true statements concerning cages by placing an "X" beside each statement that is true.

_____a. A cage is a solid trim element that serves as a guide to align movement of a valve stem.

_____b. Standard cages are available to produce linear, equal percentage, and quick opening flow characteristics in a control valve.

_____c. The advantage of a cage-guided valve is that the flow characteristics can be changed by installing a different cage; the valve plug and seat ring do not usually have to be changed.

_____d. Another advantage of cage-guided valves is that special cage designs are available to provide noise attenuation or control cavitation:

TEST

6. Complete statements concerning valve plug guiding by circling the material that best completes each statement.

   a. Valve plug guiding is required to assure that the valve plug stem moves smoothly through its travel range and to assure that the valve plug provides the correct (**valve plug/seat ring, stem-flange**) ring alignment when the valve closes.

   b. Top-and-bottom guiding is accomplished with one bushing in the bonnet of the valve, and a second bushing in the (**bottom flange, top of the cage**).

   c. Top guiding is accomplished with a single bushing in the (**valve body bonnet, bottom flange**).

   d. Top-and-port guiding is accomplished with a guide bushing in the bonnet and by the valve port body; small diameter valve plugs to control (**low, fluctuating**) flow rates are often designed with top-and-port guiding.

   e. Stem guiding is accomplished with a guide bushing in the bonnet that acts directly on the (**valve plug stem, cage**).

   f. Cage guiding is (**built in, not possible**) because the outside diameter of the valve plug is in close tolerance with the inside service of the valve body throughout the range of travel.

7. Solve problems concerning restricted-capacity valve trim by selecting the correct answer.

   a. Restricted-capacity trim is sometimes used in larger valve bodies selected for their structural strength, but restricted-capacity trim is also used in what else, high temperature applications or in valves oversized through design error?

      Answer: ______________________________

   b. Reduced-capacity trim can eliminate the need for expensive pipeline reducers, but also permit what, multi-use valve service or selection of a valve big enough for future flow requirements?

      Answer: ______________________________

8. Solve problems concerning valve plugs with groove pins by selecting the correct answer.

   a. When a valve stem is screwed into a plug, it needs also to have a groove pin for what purpose, to balance the stem or to provide additional security?

      Answer: ______________________________

   b. The hole for a groove pin is created in what way, by the stem manufacturer or it has to be drilled?

      Answer: ______________________________

TEST

9. Select true statements concerning packing by placing an "X" beside each statement that is true.

_____a. Packing is material positioned around the valve plug stem to prevent the valve bonnet from leaking, and because packing is subject to wear, replacing packing is a job that almost every technician faces from time to time.

_____b. Generally, packing is either lubricated graphite, spring-loaded graphite, or TFE in square cross-sections or V-rings.

_____c. When removing old packing, corkscrew tools are normally used because they can't damage the valve stem.

_____d. For installing new packing, packing tools are recommended because they slide down over the stem threads and permit a technician to tamp the packing in place without damaging the stem threads.

_____e. TFE packing should never be pounded into place, and all packing should be placed in order according to manufacturer's specifications.

_____f. With TFE V-ring packing, the packing nut should be tightened down as far as it will go before putting the valve back in service.

_____g. With graphite packing, the packing nut should be screwed hand tight, and then tightened as required after the valve has been put back in service.

_____h. Silicone grease is a commonly used packing lubricant, but in all cases, lubrication should follow manufacturer's specifications.

10. Select true statements concerning packing lubrication by placing an "X" beside each statement that is true.

_____a. Semi-metallic packing and graphited asbestos around a valve stem requires lubrication, and this is accomplished by removing the pipe plug and installing a lubricator or a lubricator/isolating valve.

_____b. Lubricants for standard service, high temperature service, and chemical service are all the same.

_____c. With a standard lubricator, the lubricant is placed in the lubricator and allowed to work its way into the packing.

_____d. With a lubricator/isolating valve used in high pressure service, the isolating valve has to be opened to permit lubrication, and should be closed immediately after each lubrication.

_____e. The type of lubricant and dates of lubrication should be recorded on the control valve service record so it will become a part of the control valve service history.

TEST

11. Match basic control valve types with their characteristics.

_____a. The most common body style, and generally specified for applications with stringent shutoff requirements.

_____b. These valves are usually single-ported, often used in boiler feedwater and heater drain service, and can also serve as an elbow.

_____c. Single-ported valves that require smaller actuators than other single-ported bodies, and permit trim selection for specific flow characteristics.

_____d. These valves have oversize end connections, and are designed for noise applications such as high pressure gas reducing stations.

_____e. This is a modification of the cage-guided body so that the valve can be used when push-down-to-open valve plug action is desired.

_____f. These valves reduce dynamic forces on the valve plug and can be used in high pressure drop applications or other severe service conditions with a smaller actuator than would be required on a single-ported valve.

_____g. A special valve design that can provide flow-mixing or flow-splitting, and often designed with cage trim for ease of maintenance.

1. Reverse-acting cage-guided valve bodies
2. Single-port valve bodies
3. Double-ported valve bodies
4. Angle-style valve bodies
5. Three-way valve bodies
6. High-capacity cage-guided valve bodies
7. Balanced-plug cage-style valve bodies

12. Complete statements concerning other types of valves by circling the material that best completes each statement.

a. Butterfly valve bodies provide (**medium, high**) capacity with low pressure loss through the valve.

b. Butterfly valves are economical, especially in larger sizes, but may require high output (**actuators, signals**) if the valve is big or the pressure drop is high.

c. V-notch ball control valve bodies have a straight through flow design that produces (**little, high**) pressure drop.

TEST

d. **(V-notch, Butterfly)** valves are good for handling errosive fluids or slurries containing fibers or entrained solids, and are widely used in chemical plants, the paper industry, sewage treatment plants, power plants, and petroleum refineries.

e. Eccentric-disc control valve bodies are relatively new, but the disc design and operation minimizes seal wear; they are adaptable to many control applications, **(and are often less, but are often more)** costly than globe-style valves of equal capacity.

f. Relief valves come in many shapes and sizes, and as the name implies, they are used to **(control, vent)** pressure **(from, in)** service lines.

g. **(Pinch, High-pressure)** valves are typically used for service with slurries where entrained solids in a medium would quickly wear out other types of valves.

13. Solve problems concerning control valve end connections by selecting the correct answer.

a. Screwed pipe threads are not recommended for what kind of service, high temperature or high pressure?

Answer: ______________________________

b. Ring-type flanges are excellent for high pressure applications, but are not recommended for what kind of service, high temperature or flow applications?

Answer: ______________________________

c. Welded end connections are leak-proof at all pressures and temperatures, but they are also what, expensive or difficult to remove from a line for service?

Answer: ______________________________

14. Solve problems concerning extension bonnets by selecting the correct answer.

a. Extension bonnets are used for what, only high temperature applications or both high and low temperature applications?

Answer: ______________________________

b. Bellows seal extension bonnets are used to protect both stem and packing from a process fluid, so when a plug in a bellows seal extension is leaking it indicates what, that the extension requires service or that the bellows seal is broken and should be replaced.

Answer: ______________________________

TEST

15. Select true statements concerning guidelines for control valve maintenance by placing an "X" beside each statement that is true.

_____a. Always be certain that all line pressure is shut off and released from the valve body, and also be certain that all pressure to the actuator is cut off and captive pressure gradually relieved.

_____b. When replacing stem packing, make sure there is no pressure in the valve body before starting to remove the packing nuts.

_____c. Seat rings are subject to wear, especially in severe service conditions, and a seat ring puller should always be used on threaded seats.

_____d. Lapping or grinding metal seats in globe valves will normally restore good valve plug closing, and the grinding can be accomplished only with precision tools and expensive grinding compounds.

_____e. Snug up flange bolts gently at first to assure proper flange alignment, then tighten the bolts in a criss-cross pattern to avoid uneven gasket loading or damage to the flange.

_____f. On valves with screwed connections, use a good grade of pipe sealant on the male threads only, but do not use sealant on the female threads in the valve body because excess sealant could be forced into the valve body and impair its performance.

16. Solve problems concerning diaphragm actuators by selecting the correct answer.

a. Diaphragm actuators use molded diaphragms that can be replaced how, with expertise and a fair amount of time or with relative ease and speed?

Answer: ____

b. Diaphragm actuators are classified as what, air-to-lower and air-to-raise or direct acting or reverse acting or do both terms apply?

Answer: ____

17. Complete statements concerning electromechanical actuators by circling the material that best completes each statement.

a. Electromechanical actuators are driven by either ac or dc motors, and they are frequently used to actuate large valves because they can deliver extremely (**high thrust and high torque, fast response**).

b. An assortment of (**accessories for, types of**) electromechanical actuators permits them to be used with both sliding stem and rotary control valves.

TEST

c. In modern electromechanical actuators, the torque and limit switches that control stem movement are readily accessable inside the switch compartment cover, and both torque and limit can be set with (**a screwdriver, a calibration tool**).

d. Manual handwheels are often integrated on electromechanical actuators with (**a stop switch, lever-operated clutches**) that permit override of the power operation in the event manual control of the valve is ever needed or desired.

18. Select true statements concerning piston actuators by placing an "X" beside each statement that is true.

_____a. Piston actuators are also pneumatically operated, and usually operate at high pressure to provide maximum thrust output and quick response.

_____b. Piston actuators are in common use with butterfly valves, rotary-shaft control valves, and relief valves.

_____c. Piston actuators are used mostly in applications that require positive on/off valve service, but can also be used with a positioner for throttling service.

19. Complete statements concerning handwheel and handlever actuators by circling the material that best completes each statement.

a. Handwheel and handlever actuators provide a manual means for controlling control valves and other valves, and both types see service in (**all sorts of industrial applications, limited applications**).

b. Handwheel actuators have special travel indicators, some marked in $1/64$" graduations to provide precise valve positioning, and (**a good visual indication, electrical tracking**) of valve position to take guesswork out of manual operation.

c. Manual rotary actuators are designed for use on rotary-shaft valve bodies, butterfly valve bodies, and (**ball valve bodies, high temperature applications**).

d. As with the valves they service, manual rotary actuators are either direct acting or reverse acting, and travel indicators and (**direction, rate**) of operation are clearly marked on the actuator housing.

e. Handlever actuators are used on spline-shaft rotary valves, ball valves, and butterfly valves and provide (**general, accurate**) positioning for (**specific, general**) flow requirements.

TEST

20. Select true statements concerning valve positioners by placing an "X" beside each statement that is true.

_____a. When an air-operated control valve/actuator cannot respond to very small changes in diaphragm pressure, a pneumatic valve positioner is used to enhance valve positioning.

_____b. Because of a feedback arrangement from the control valve, a positioner has the sensitivity needed to react to very small changes in pressure and accomplish valve stem movement with speed and precision.

_____c. Since some valves are designed for other than the 3-15 psi standard, a valve positioner can be used to compensate for non-standard service.

_____d. In a split-range application where two ro more control valves are responding to output from a single controller, a positioner permits each valve to respond to a given range.

_____e. Split-range installations are common in the condenser make-up water systems in power generating plants.

_____f. Some positioners are available with optional cams that can be adjusted to modify the flow characteristic of a control valve to linear, equal percentage, quick opening, or square root.

_____g. In addition to pneumatic positioners, electro-pneumatic positioners are available but not in common use.

_____h. In certain critical service where a controller needs to know the exact position of a valve at all times, position sensors are used to send the proper signal back to a controller.

_____i. Motion transmitters typically transmit a pneumatic output signal which is directly proportional to the valve stem position, and are used with all types of indicating and recording equipment.

21. Solve problems concerning safety in control valve/actuator service by selecting the correct answer.

a. In removing a control valve from service, safety has a two-fold objective, to protect personnel, and what else, to permit careful inspection of a problem or to keep from having to shut the system down?

Answer: ____

b. For control valve service, the industry standard has become what, redundant service lines or the service bypass?

Answer: ____

TEST

22. Complete statements concerning troubleshooting control valve/actuator subsystems by circling the material that best completes each statement.

    a. Final element subsystems are among the easiest parts of a system to troubleshoot (**because the problems are easy to identify, but problems are difficult to identify**).

    b. The control valve/actuator should be evaluated together because they are normally placed into service (**as a matched pair, at the same time**).

    c. Always check supply air with a calibrated gauge to make sure it is at the proper psi; if supply air is okay, then the (**actuator or valve is, lines are**) at fault and a quick visual inspection may identify the problem.

    d. If the actuator doesn't work, it should be replaced, but if it moves smoothly through its full range, then (**the valve, supply air**) is at fault and should be replaced.

    e. NEVER attempt to remove a control valve until you are certain that the supply air line is out of service and that all pressure has been (**removed, checked**).

    f. When replacing a valve (**cage, plug**), always use a new valve stem because a new hole will have to be drilled in the stem and an old stem will not hold up in service.

    g. When a valve or actuator is repaired or replaced, (**recalibration, a test run**) of the total final element subsystem is required.

23. Select true statements concerning troubleshooting other final elements by placing an "X" beside each statement that is true.

    ______a. Motors used as final elements have to be evaluated with proper meters to check for current draw and proper voltage.

    ______b. Tachometers or strobe lights are used to check motor speeds.

    ______c. Stepper motors should be monitored with a DVOM to determine if the proper pulse waveforms are present as specified by the manufacturer.

    ______d. In all troubleshooting activity, it is extremely important to have the manufacturer's data available, and to follow all instructions carefully.

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

24. Demonstrate the ability to:

    a. Disassemble, inspect, and reassemble a glove-type control valve. (Job Sheet #1)

    b. Adjust valve plug travel on an actuator. (Job Sheet #2)

TEST

c. Adjust range on an actuator. (Job Sheet #3)

d. Replace the diaphragm on an air-to-lower actuator. (Job Sheet #4)

e. Replace the seat-ring on a globe-type control valve. (Job Sheet #5)

ACTUATORS, POSITIONERS, AND CONTROL VALVES
UNIT V

ANSWERS TO TEST

1.	a.	8	h.	13
	b.	4	i.	1
	c.	12	j.	9
	d.	6	k.	5
	e.	2	l.	3
	f.	10	m.	7
	g.	11		

2.	a.	5	f.	13	k.	3
	b.	7	g.	2	l.	11
	c.	10	h.	14	m.	9
	d.	1	i.	8	n.	4
	e.	12	j.	6		

3. a. 1) Seat ring
   2) Direct acting valve
   3) Valve stem plug
   4) Reverse acting valve
   b. 1) Closed
   2) Open
   3) Fail-safe valve
   4) Low
   5) High
   c. In the direction of
   d. In and Out
   e. Upstream, downstream
   f. Throttling

4. a. Linear flow
   b. Equal percentage flow
   c. Quick opening flow

5. b, c, d

6. a. Valve plug/seat ring
   b. Bottom flange
   c. Valve body bonnet
   d. Low
   e. Valve plug stem
   f. Built in

ANSWERS TO TEST

7. a. Valves oversized through design error
   b. Selection of a valve big enough for future flow requirement

8. a. To provide additional security
   b. It has to be drilled

9. a, b, d, f, g, h

10. a, d, e

11. a. 2 e. 1
    b. 4 f. 3
    c. 7 g. 5
    d. 6

12. a. High
    b. Actuators
    c. Little
    d. V-notch
    e. And are often less
    f. Vent, from
    g. Pinch

13. a. High temperature
    b. High temperature
    c. Difficult to remove from a line for service

14. a. Both high and low temperature applications
    b. That the bellows seal is broken and should be replaced

15. a, b, c, e, f

16. a. With relative ease and speed
    b. Both terms apply

ANSWERS TO TEST

17. a. High thrust and high torque
    b. Accessories for
    c. A screwdriver
    d. Lever-operated clutches

18. a, c

19. a. All sorts of industrial applications
    b. A good visual indication
    c. Ball valve bodies
    d. Direction
    e. Accurate, specific

20. a, b, c, d, e, f, i

21. a. To keep from having to shut the system down
    b. The service bypass

22. a. Because the problems are easy to identify
    b. As a matched pair
    c. Actuator or valve
    d. The valve
    e. Removed
    f. Plug
    g. Recalibration

23. a, b, d

14. a. Evaluated according to criteria in Practical Test #1
    b. Evaluated according to criteria in Practical Test #2
    c. Evaluated according to criteria in Practical Test #3
    d. Evaluated according to criteria in Practical Test #4
    e. Evaluated according to criteria in Practical Test #5

CONTROLLERS AND CONTROLLER TUNING

UNIT VI

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss the functions of proportional, integral, and derivative control modes in controller applications. The student should also be able to discuss gain and proportional band and their roles in controller performance, and tune a controller. These competencies will be evidenced by correctly completing the procedures outlined in the assignment and job sheets and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to controllers and controller tuning with their correct definitions.
2. Select true statements concerning open loop control.
3. Complete statements concerning closed loop control.
4. Complete statements concerning gain and proportional band.
5. Select true statements concerning basic controller action.
6. Select true statements concerning proportional control.
7. Complete statements concerning integral control.
8. Complete statements concerning integral time and reset rate.
9. Complete statements concerning derivative control.
10. Select true statements concerning dynamics of controller tuning.
11. Identify damping profiles.

OBJECTIVE SHEET

12. Solve problems concerning controller applications.

13. Solve problems concerning controller tuning basics.

14. Solve problems concerning basic tuning for flow loops.

15. Solve problems concerning basic tuning for level loops.

16. Complete statements concerning cascade control.

17. Solve problems concerning tuning cascaded controllers.

18. Solve problems concerning tuning interactive controllers.

19. Complete statements concerning feed forward control.

20. Select true statements concerning distributed control systems.

21. Complete statements concerning programmable logic controllers.

22. Evaluate controller performance. (Assignment Sheet #1)

23. Demonstrate the ability to tune an electronic controller in an air-flow control loop. (Job Sheet #1)

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information and assignment sheets.

C. Make transparency.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Discuss and demonstrate the procedures outlined in Job Sheet #1, and note that the job sheet requires preliminary calibration of several test instruments. Review the job sheet to make sure appropriate materials are available to set up the control system depicted in Figure 1 of Job Sheet #1, and arrange for students to complete the job sheet in several stages because it is a lengthy activity that will consume anywhere from 6 to 8 hours. Inform students that results may vary, but impress upon them the need for the Ziegler-Nichols tuning procedure because it is commonly used in industry and provides the basics for other methods of controller tuning.

G. Invite a manufacturer's representative to talk to the class about controllers and how their applications are related to the processes they serve.

H. Invite a technician from a local or area industry that uses controllers in a process system to talk to the class about controller tuning and the procedure used in that specific facility.

I. Review materials related to dead band, offset, gain, and proportional band so students will have a better grasp of elements important to controller design and controller tuning.

J. Give test.

REFERENCES USED IN DEVELOPING THIS UNIT

A. Jury, Floyd D. Technical Monograph 28, *Fundamentals of Three-Mode Controllers*. Marshalltown, IA 50158: Fisher Controls, 1973.

B. Jury, Floyd D. Technical Monograph 32, *Fundamentals of Closed Loop Control*. Marshalltown, IA 50158: Fisher Controls, 1975.

C. Meier, W. J. *Guide to Controller Tuning*. Ponca City, OK 74602: Engineering Department, Project and Construction Division, CONOCO, 1986.

D. *Process Measurement and Control Terminology, SAMA Standard PMC 20.1-1973*. New York, NY 10017: Process Measurement and Control Section, Inc., Scientific Apparatu Makers Association, 1973.

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

INFORMATION SHEET

I. **Terms and definitions**

   A. Controller — A device which operates automatically to regulate a controlled variable by adjusting the gain of a control loop to fit system dynamics

   B. Damping — A method by which oscillation in a control loop is reduced or suppressed

   C. Dead band — The range of an input change required to activate a response from a control device

   D. Deviation — The degree to which a system exceeds or drops below setpoint after a disturbance

   E. Gain — Generally the sensitivity of an element to changes in its input, and specifically, the ratio of output magnitude to a change in input magnitude

   F. Transient condition — A period after a disturbance when rapid, high frequency signals enter a process

   G. Steady-state — An operating condition that exhibits minimal change over an extended period of operation

   H. Oscillation — The tendency of a process to fluctuate back and forth and remain unstable in response to high gain or too high a gain in a control loop

   I. P (proportional) — A control mode that produces a change in output proportional to a change in input

   J. I (integral) — A control mode that moves a process back to or close to setpoint after a disturbance; also called reset

   K. D (derivative) — A control mode that anticipates a disturbance and responds rapidly to keep the error from increasing; also called rate

   L. PID controller — A controller which has proportional, integral, and derivative control modes integrated into a single unit

II. **Open loop control**

   A. Open loop control is the simplest type of process control.

   B. Open loop means there is no direct measurement of the controlled variable, and therefore no feedback to help compensate for changes in system input.

INFORMATION SHEET

C. On/off control strategies are open loop systems because some systems still require a person to monitor a gauge or level, and turn a valve on or off in response to a high or low level in a sight glass.

D. On/off control strategies more frequently place a control mechanism on the level or gauge output so that it will turn a valve on/off as system input requires.

E. On/off control strategies have brought significant changes to instrumentation:

   1. Since technicians or operators were freed from having to monitor indicators, they could perform other duties.

   2. Since the valve had to be turned on/off frequently, automatic devices were developed to perform this function.

F. Oscillation in the control valve is characteristic of on/off controls, and an adjustment called "dead band" is used to control oscillation.

G. Dead band is the amount of input required before a control device responds to the input.

   EXAMPLE: A home furnace well demonstrates on/off control with dead band because the thermostat has several degrees of temperature dead band between the on/off settings, and this helps keep the furnace from being constantly turned on, then off, which is the equivalent of oscillation.

H. Open loop on/off controls are not only subject to oscillation in the control valve, frequent load variations still require manual monitoring and manual adjustment of the loop, and automatic closed loop systems were developed to help solve these and other control problems.

III. Closed loop control

A. Closed loop control means that a control system has:

   1. A means to measure the controlled variable and generate feedback;

   2. A capability to compare the controlled variable measurement with setpoint to determine if there is a deviation;

   3. The means to provide a corrective adjustment to an actuator/control valve to compensate for the deviation.

B. The capability of a controller to receive feedback information and compare that information with setpoint is the heart of all automatic closed loop control strategies.

INFORMATION SHEET

IV. Gain and proportional band

A. In a control loop itself, the process receives an input and provides some kind of output; the ratio of the change in output magnitude to the change in input magnitude is known as GAIN.

B. The rule of thumb is: the higher the gain, the greater the output change for a given input.

C. Gain expresses the sensitivity of an element to changes in its input; this means that a device with high gain is very sensitive to input changes.

D. Since the function of a controller is to compensate for load changes, this requires a GAIN adjustment, or a PROPORTIONAL BAND adjustment.

E. The GAIN adjustment on a controller and the PROPORTIONAL BAND adjustment have an inverse relationship: (Transparency 1 and Handout #3)

   1. Narrowing the proportional band is the same as increasing gain;

   2. Widening the proportional band is the same as decreasing gain.

F. Since high gain promotes good control, it would seem that setting a controller on a high gain (a narrow proportional band) would solve all problems, but high gain can lead to another testy problem called instability.

G. Instability takes a system into excessive oscillation which can cause a control valve to keep moving up and down.

H. To avoid instability, the gain can be lowered (the proportional band broadened), but this produces sluggish system performance.

I. To have high gain for good performance at the risk of instability or to have low gain for poor performance with no risk of instability created the dilemma that controller designers have attempted to solve.

V. Basic controller action

A. There are three types of controller action:

   1. P or proportional controller action produces a change in output in proportion to the change in input, the error, but P action will not always return a control loop to setpoint.

   2. I or integral action moves a control loop back to or close to setpoint after an error and is also called RESET action. I action is combined with P action in the design of PI controllers.

   3. D or derivative controller action anticipates an error and responds rapidly to prevent the error from becoming too large. Derivative action is also called RATE, and D action is combined with P and I action in the design of PID controllers.

INFORMATION SHEET

B. Each controller action provides a particular response to an error or a change in input, and controller action can best be demonstrated by examining the P, I, and D functions in a three-mode PID controller.

VI. Proportional control

A. When a control loop experiences an abrupt full load upset, the pressure on the actuator diaphragm must decrease in order to allow the control valve to open and accommodate the increased flow.

B. The amount of pressure decrease required to fully open the control valve is called OFFSET.

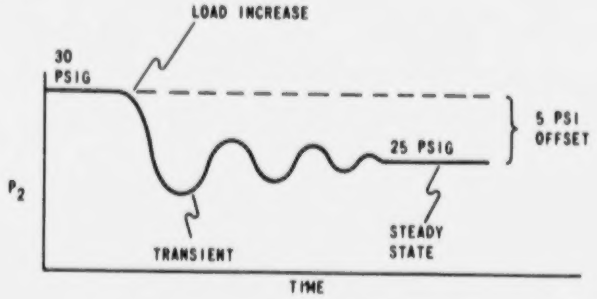
C. Since the amount of OFFSET required to open the valve is proportional to the change in load, this type of control action is called PROPORTIONAL CONTROL.

D. One of the problems with proportional control is that an upset has a transient condition which results in extremely poor system performance. (Figure 1)

E. Another problem with proportional control is that the offset must continue as long as the load continues at its new flow rate. (Figure 1)

(NOTE: Notice in Figure 1 that the controlled pressure (P_2) tends to drop a lot more than the calculated 5 psi during the transient condition and that the 5 psi offset represents a wide proportional band and low gain which generally results in poor system performance.)

FIGURE 1



Courtesy Fisher Controls Company

F. By adding a proportional controller to the system depicted in the example, the sensitivity of the system to an upset can be increased by increasing the gain on the controller. (Figure 2)

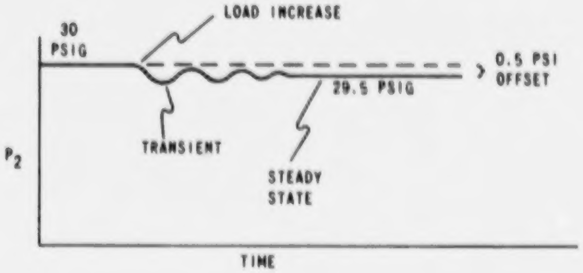
G. Sensitivity means that the loading pressure required to fully open the valve is decreased greatly so that the transient condition of the upset is better controlled.

INFORMATION SHEET

H. The high gain made possible by the proportional controller returns the system to a steady-state operation with minimal change in system performance, and the new steady-state operation will be much closer to the original setpoint. (Figure 2)

(NOTE: Imagine that the controller gain in Figure 2 has been set at 10. This means that the offset produced by the upset is only 0.5 psi instead of the 5 psi as reflected in Figure 2. This significantly improves system performance.)

FIGURE 2



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I. It would seem that a proportional controller set to a high gain would provide ideal loop control, but high gain can cause a system to oscillate back and forth in an unstable manner.

VII. Integral control

A. An instability problem with a proportional controller can be solved by reducing the gain to broaden the proportional band, but the lower gain results in a larger steady-state offset and less than desired performance.

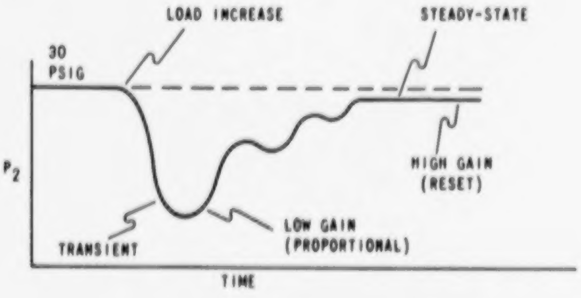
B. To avoid a large steady-state offset, RESET action can be added to a controller.

C. A proportional controller with RESET introduces a gain reduction during the transient portion of a disturbance, and this prevents the system from oscillating in an unstable manner. (Figure 3)

INFORMATION SHEET

D. After the proportional action in the controller manages to get the transient condition under control, the RESET action moves the controller back to a high gain condition where the steady-state offset is very close or back to original setpoint. (Figure 3)

FIGURE 3



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E. RESET action is also referred to an INTEGRAL, and a controller with proportional and integral action is called a PI controller.

F. One important characteristic of PI control action is that in order to keep the system stable, the high gain of the controller has to be sacrificed during the transient condition.

G. With PI control action, the RESET signal has to be delayed just enough to match the recovery characteristics of the process under control:

1. If gain increases too rapidly, the system will be unstable;
2. If gain increases too slowly, the system will be sluggish.

VIII. **Integral time and reset rate** (Transparency 2)

A. The rate at which a controller repeats corrective action required to reduce offset requires integral action.

B. The rate at which corrective integral action is repeated is expressed in two ways:

1. Reset rate or repeats per minute.
2. Integral time or minutes per repeat.

C. Reset rate and integral time have an inverse relationship similar to gain and proportional band. (Transparency 2)

D. Integral action is required to bring a measured variable back to setpoint after an upset, and how often the corrective action is repeated is a function of reset rate or integral time.

INFORMATION SHEET

E. The integral time settings used in controller tuning should be related to the response time of the loop being controlled.

EXAMPLE: A flow loop with only a sensor, valve, and controller would probably respond quickly, but in a large vessel controlled by pressure the large volume could create a lag time of several minutes.

F. It is difficult to tune integral action without an estimate of the response time the loop requires.

G. A constant cycle in a loop is usually an indication of too short an integral time.

IX. Derivative control

A. In PI control, an upset is immediately answered with a reduction of controller gain so that the system will remain stable.

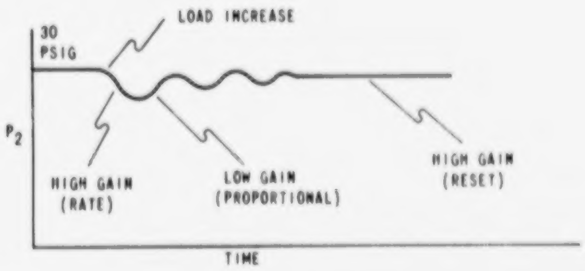
B. Immediate reduction of controller gain means that transient control suffers, and the way to avoid rapid gain reduction is to add RATE action to a PI controller.

C. Since RATE is also referred to as DERIVATIVE action, a controller with all three types of action is called a PID controller.

D. The advantage of full PID action is that the RATE action can delay the rapid gain reduction just long enough for the system to begin responding to the load disturbance, but not so long that the system becomes unstable. (Figure 4)

(NOTE: Observe in Figure 4 how the transient condition has been held to a minimum with full PID control. Compare it with Figure 3 to fully appreciate the difference.)

FIGURE 4



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INFORMATION SHEET

E. In ideal PID control, a step change in the load is handled in the following sequence:

1. The RATE control momentarily maintains the high gain to improve initial response to the transient condition;
2. The PROPRTIONAL control reduces the gain during the major part of the transient condition to maintain stability;
3. As the system again approaches steady-state operation, the RESET control slowly increases the gain back to its high steady-state value; in other words, back to or close to setpoint.

X. Dynamics of controller tuning

A. In every control loop there is a critical frequency where disturbances tend to reinforce themselves; when disturbances do occur, many loops have a tendency cycle at this frequency.

B. The point where a loop cycles in response to a disturbance is referred to as the system cycling frequency or the critical frequency.

C. A rule of thumb is that to keep a loop from becoming unstable, the loop gain must be sufficiently low at the critical frequency.

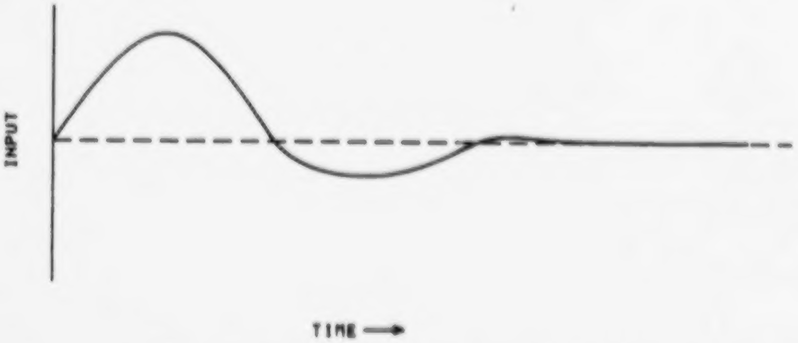
XI. Damping profiles

A. Damping refers to the time it takes to reduce or supress oscillation in a system.

B. Since "damping" is a term used in some controller literature, technicians need to know how to interpret characteristic damping profiles on a recorder.

C. When each progressive wave from a disturbance is ¼ the height of the previous wave, this is called ¼ wave damping. (Figure 5)

FIGURE 5



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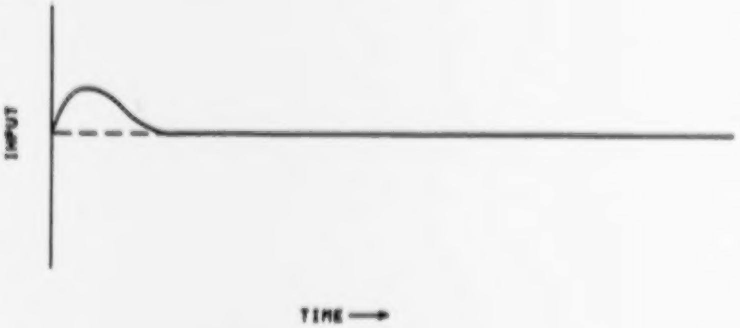
INFORMATION SHEET

D. Sometimes an upset can send a measured variable past setpoint, but response to the upset is so fast that no overshoot is observed, and the control loop is said to be "critically damped." (Figure 6)

FIGURE 6



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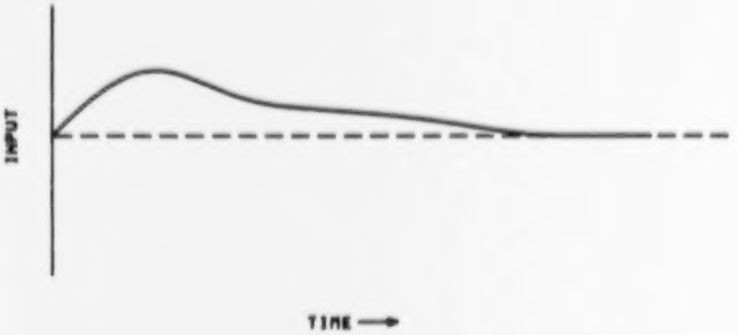
E. When response to an upset is very slow and no overshoot is observed, the control loop is said to be "overdamped." (Figure 7)

FIGURE 7



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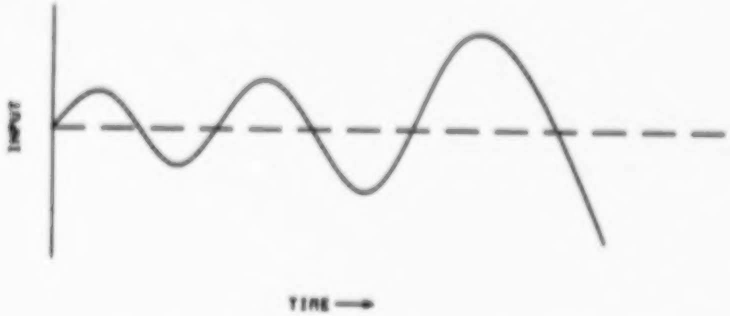
F. When response to an upset produces a condition where each progressive wave is higher than the previous wave, the loop is said to be "unstable." (Figure 8)

FIGURE 8



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G. Both overdamped and unstable loop performance is undesirable and most loops are tuned somewhere between ¼ wave damped and critically damped so that a controller can control as smoothly and tightly as possible.

XII. Controller applications

A. It would seem that a PID controller would be perfect for almost every application, but this is not the case.

B. In level applications where an offset is not a big problem, proportional controllers can do the job and are in common use.

*C. PI controllers may be the most commonly used controllers of all; PI controllers are used on level, temperature, flow, and many other loops.

D. PID controllers are typically used on critical temperature loops where dead band is wide and process change is fast.

(NOTE: Derivative control will not help in level control or flow control loops, and PID controller tuning should be delegated to experienced personnel only.)

XIII. Controller tuning basics

A. Experienced control people agree that the most realistic method for tuning a controller is to tune it around the actual system being controlled.

INFORMATION SHEET

B. Every control loop has a critical frequency where the gain must be kept sufficiently low for the system to remain stable.

C. It is not necessary to know the critical frequency of the system in order to tune a controller because part of the tuning procedure is to find that frequency as it exists in actual operation.

D. Preliminary to all controller tuning, it is wise to record the current controller setting before beginning the tuning process.

XIV. Basic tuning for flow loops

A. For simple flow loops, integral action is usually the primary control action.

B. To tune most flow loops, the following values are adequate:

Valve Size	Gain	Integral Time
6" or less	.5	8 seconds
Larger than 6"	1	12 seconds

C. Long tubing runs in pneumatic loops may add several seconds to integral time.

D. To tune a simple flow loop more accurately, set the gain at a minimum (maximum for PB), and set integral time to the appropriate value.

E. Increase the gain slowly, 50% every 1 minute, until the flow starts to oscillate.

F. Set the gain at ½ the value at which the flow oscillated.

XV. Basic tuning for level loops

A. For most level loops, the actual level in the vessel is unimportant as long as level stays in a measurable range.

B. In many level loops, integral action may not be necessary, and in the case of noncritical vessel level, the rule of thumb is:
Gain = 1 to 2
Integral Time = 20 minutes

C. The gain for a level loop can also be determined based on the error that will be tolerated.

INFORMATION SHEET

D. The gain calculation is based on the maximum change in valve position, and the maximum change in level; in notation it is stated as: Gain = Maximum Change in Valve Position/Maximum Input Error

EXAMPLE: Valve normally 40% open
Level is to be contained between 80% to 20%
Setpoint is 50%
Gain = (100% − 40%)/(80% − 50%)
Gain = 2.0 (PB = 50)
or
Gain = (40% − 0%)/(50% − 20%)
Gain = 1.33 (PB = 75)

E. The gain for the loop in the previous example would be 2.0 since the valve would be stroked fully open or closed at the defined limits.

F. It should be noted that integral action can cause a level loop to cycle if the disturbance is cyclic, and within the period of the integral time.

G. When level is critical, more accurate tuning techniques should be used to establish controller parameters.

XVI. **Cascade control**

A. In a normal cascade loop, there are two controllers, one called a primary (master) and the other a secondary (slave).

B. The output from the secondary controller moves the control valve while the primary controller provides setpoint for the secondary controller.

C. The real purpose of a cascaded loop is to minimize disturbances or errors in a secondary loop, and is used when the desired control point such as temperature, is slow compared to the manipulated variable which is probably flow.

XVII. **Tuning cascaded controllers**

A. When tuning a cascaded loop, always begin with the secondary controller and move to the primary.

B. Remove the secondary controller from the cascade mode and tune the secondary loop to ¼ wave damping for crisp response.

C. Check the integral time in the primary controller to assure that it is 3 to 5 times longer than the integral of the secondary. If it is not, the primary loop should be tuned slower.

D. Check the integral time of the secondary controller. If it is less than 1 minute, the loop should not be cascaded.

INFORMATION SHEET

E. Another rule of thumb is that two loops of similar speed should not be cascaded.

F. When calculating tuning parameters for the primary controller, convert the output to a percent of output change to provide the proper proportional band.

XVIII. Tuning interactive controllers

A. Interaction between controllers creates common problems in tuning when both controllers have been tuned. When both controllers are placed in automatic, the process cycles.

(NOTE: This can happen when a design tries to control flow and pressure with two controllers and two control valves.)

B. Handle the tuning problem in order:

1. Retune one controller so it responds much slower than the other controller;
2. Tune the most important controller first, then tune the other controller so that it does not cause excessive cycling in the most important controller;
3. Minimize the interaction by moving the valves farther apart, or eliminate one of the controllers.

C. Continued problems with controller interaction points to a need for a control engineer or experienced instrumentation technician to review the problem.

XIX. Feed forward control

A. Feed forward is a control scheme that uses information about conditions that could upset a controlled variable, and takes corrective action to minimize upsets of the controlled variable.

B. Feed forward is different from other control schemes in that the scheme uses process information that could upset the controlled variable, but the scheme does not use information from the controlled variable itself.

C. When a process is difficult to control with feedback loops, a feed forward scheme might be used, and in cases where quality control is critical, feed forward control can sometimes effect improved control.

D. A feed forward control scheme is based on equations that demand a in-depth knowledge of a process and its instrumentation, and technicians working with a feed forward scheme need advanced skills or the help of an engineer.

INFORMATION SHEET

XX. Distributed control systems

A. To take advantage of the speed, communications capabilities, and the analytical power of computers, many process industries have installed distributed control systems.

B. As the name implies, a distributed control system has individual microcomputers distributed at important locations in a system with a host microcomputer to control the system.

C. The distributed units communicate with each other and with the host computer over a data bus that forms a high-speed communications network.

D. Distributed controls are attractive because of their speed and accuracy, and also because their modular design permits the location of all systems monitoring at a central location.

E. CRT monitors in a distributed control console provide visual displays of total system functions so operators and technicians can evaluate performance and isolate trouble spots almost instantly.

F. Distributed control systems are interfaced with printers to provide automatic printing of selected data at the end of intervals ranging from one minute to many hours or end-of-period logs such as the end of a shift, day, week, or month.

G. Distributed control systems constantly exchange process information for updating and evaluation, which makes them more reliable than controller-based systems.

H. An instrumentation technician working in an installation with distributed controls should make it a point to learn the system and appreciate the assistance it provides for evaluation and troubleshooting.

XXI. Programmable logic controllers

A. Programmable logic controllers are basically microcomputers usually dedicated to discreet (ON/OFF) sequential functions such as starting or stopping motors or activating solenoids.

B. Recent PLC designs incorporate both discreet and analog functions for a combination of power and speed that makes them attractive alternatives to other control devices.

C. The capability of analog functions has expanded PLC application potential to the point they are replacing proportional and integral functions in controllers.

INFORMATION SHEET

EXAMPLE: A PLC could control a pump motor while controlling the proportional and integral control modes in a flow or level loop, and the same PLC could also provide alarm and trip functions necessary for system protection.

D. PLCs not only function as controllers, they can be effectively integrated with various measuring and control instruments and promise to earn a prominent place in process instrumentation.

(NOTE: Skills in PLC programming and installation are presented in MAVCC's *Programmable Logic Controllers*.)

Gain to Proportional Band Conversion Table

Proportional Band = 100/Gain

Gain	Proportional Band
0.10	1000
0.20	500
0.30	333
0.40	250
0.50	200
0.60	167
0.70	143
0.80	125
0.90	111
1.0	100
1.2	83
1.4	71
1.5	67
1.6	63
1.8	56
2.0	50
2.5	40
3.0	33
3.5	29
4.0	25
5.0	20
6.0	17
7.0	14
8.0	13
9.0	11
10.0	10

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Repeats/Minute To Minutes/Repeat Conversion Table

Repeats – Minutes = 1 Minutes/Repeat

Repeats/Minute	Minutes/Repeat
0.01	100
0.02	50
0.03	33
0.04	25
0.05	20
0.06	17
0.07	14
0.08	13
0.09	11
0.10	10
0.20	5.0
0.30	3.3
0.40	2.5
0.50	2.0
1.0	1.0

Repeats/Minute	Seconds/Repeat
2.0	30
3.0	20
4.0	15
5.0	12
6.0	10
7.0	8.6
8.0	7.5
9.0	6.7
10	6.0

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CONTROLLERS AND CONTROLLER TUNING
UNIT VI

HANDOUT #1 — PNEUMATIC CONTROLLER DESIGN

The following materials and illustrations are adapted from materials published and copyrighted by Fisher Controls Company and are reprinted with permission.

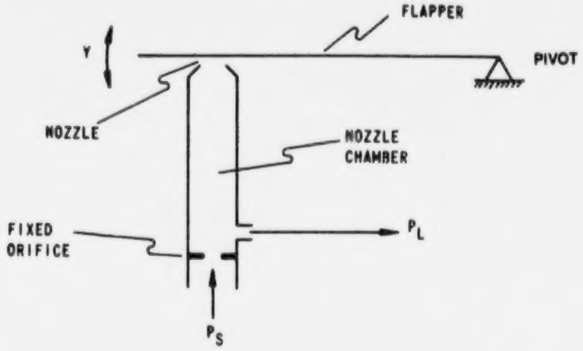
Purpose

The basic nozzle-flapper amplifier is the key component in many pneumatic control instruments. The force balance principle lends itself well to PID controller design, and technicians who have to work with force balance instruments or tune pneumatic controllers will have a better understanding of instrument objectives by examining PID controller design.

The Nozzle-Flapper Amplifier

A basic nozzle-flapper amplifier has a source of supply pressure which is fed into the nozzle chamber through a fixed orifice. The supply pressure (P_S) usually comes from a separate compressed air system, and as it is fed into the chamber, a nozzle opening which is larger than the fixed orifice, allows the flow to escape. One end of the flapper is attached to a pivot, but the free end of the flapper undergoes an input motion (Y) as flow escapes from the nozzle opening. Because of flapper motion, the flow area of the nozzle changes and varies the pressure in the nozzle chamber. The significant part of the design is that the nozzle pressure can be used as an output loading pressure (P_L) to some other device. (Figure 1)

FIGURE 1



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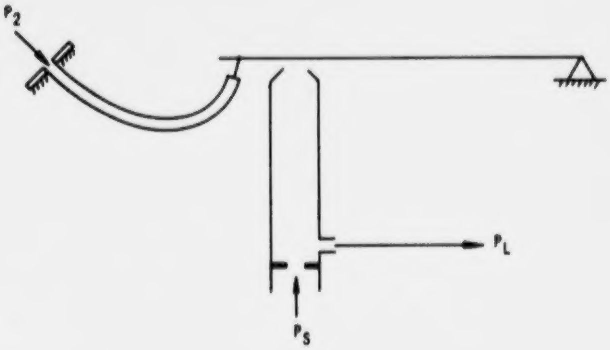
HANDOUT #1

The Flapper-Nozzle Amplifier with Bourdon Tube

By adding a curved Bourdon tube to the flapper-nozzle design, things begin to happen. The sealed, free end of the Bourdon tube is attached to the movable end of the flapper. The open end of the Bourdon tube is secured to the frame so that it can receive the controlled input pressure (P_2). As input pressure (P_2) increases, the Bourdon tube pulls downward in an attempt to straighten itself, and this flapper motion tends to restrict the flow out of the nozzle. This causes an increase in the output loading pressure (P_L). With the addition of the Bourdon tube, the flapper-nozzle amplifier has become a system in which output pressure (P_L) is rather sensitive to changes in input pressure (P_2). In other words, the system has become a rather high gain pneumatic amplifier. (Figure 2)

FIGURE 2



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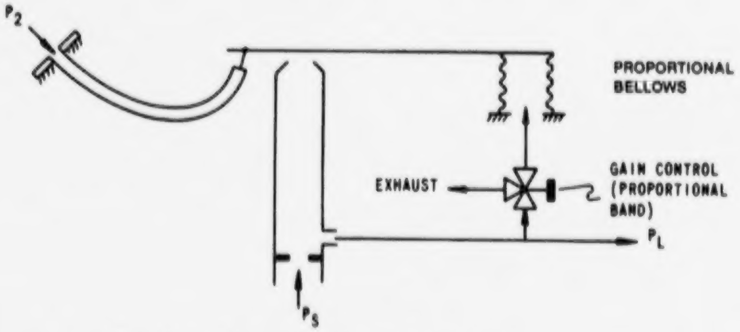
The Pneumatic Proportional Controller

The flapper-nozzle/Bourdon tube design provides a constant high gain, but the gain cannot be adjusted without changing the design. To make a basic controller, the fixed pivot on the flapper is replaced with a bellows. The output loading pressure (P_L) is tapped and fed into an adjustable three-way valve. The three-way valve acts as a splitter to send part of the output signal to the bellows and exhaust the remainder of the output signal to atmosphere.

We have already seen that when there is a change in input pressure (P_2), the action of the flapper-nozzle changes the output loading pressure (P_L). Part of the output pressure change is fed to the bellows in such a way as to *decrease* the effect that input pressure (P_2) has upon output pressure (P_L). Technically, this is called ***negative feedback***. Negative feedback is the heart of closed loop control, and an increase in negative feedback causes a decrease in gain or sensitivity of a controller. Since the output loading pressure is in proportion to the change in input pressure, there must always be some offset in the input pressure (the controlled variable) in order to accommodate changes in the load flow. This is why the device in Figure 3 is called a proportional controller. In fact, the negative feedback adjustment on the controller is called the GAIN or PROPORTIONAL BAND control. The bellows was added to the system to provide a means to cut the gain of the controller and broaden the proportional band. (Figure 3)

HANDOUT #1

FIGURE 3

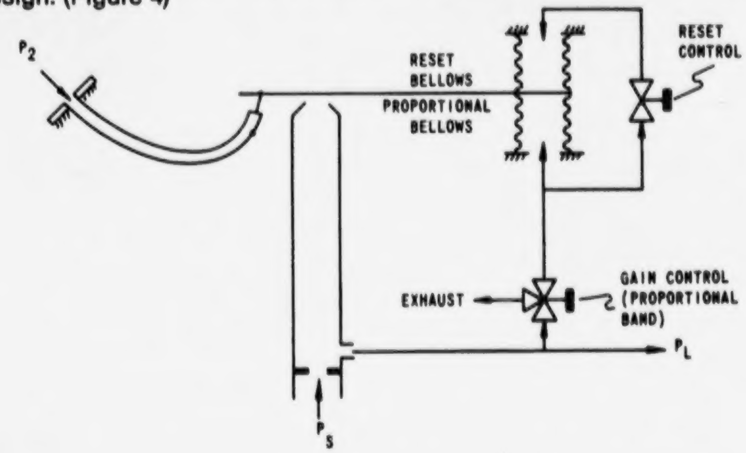

P2
PROPORTIONAL BELLOWS
EXHAUST
GAIN CONTROL (PROPORTIONAL BAND)
PL
PS

Courtesy Fisher Controls Company

Reset Control

With a proportional controller, steady-state offset can be held to a minimum by keeping the controller at high gain. However, since high gain creates problems with stability, a controller needs a means of automatically varying the gain in response to a load disturbance. This is accomplished by adding a second bellows and an adjustable needle valve to the proportional controller design. (Figure 4)

FIGURE 4


P2
RESET BELLOWS
PROPORTIONAL BELLOWS
RESET CONTROL
EXHAUST
GAIN CONTROL (PROPORTIONAL BAND)
PL
PS

Courtesy Fisher Controls Company

The reset bellows is located opposite the proportional bellows, and the two bellows have the same operating characteristics. When the pressure in the bellows is the same, one bellows cancels the effect of the other, and the system retains its high gain. Note that the pressure sent to the proportional bellows is the same pressure sent to the reset bellows, but before the pressure can reach the reset bellows, it has to go through the adjustable needle valve which is the RESET control. The single purpose of the reset valve is to provide an adjustable time delay. The more restriction adjusted into the reset valve, the longer it will take a change in pressure to register in the reset bellows. The signal that goes to the reset bellows is, technically, *posi-*

HANDOUT #1

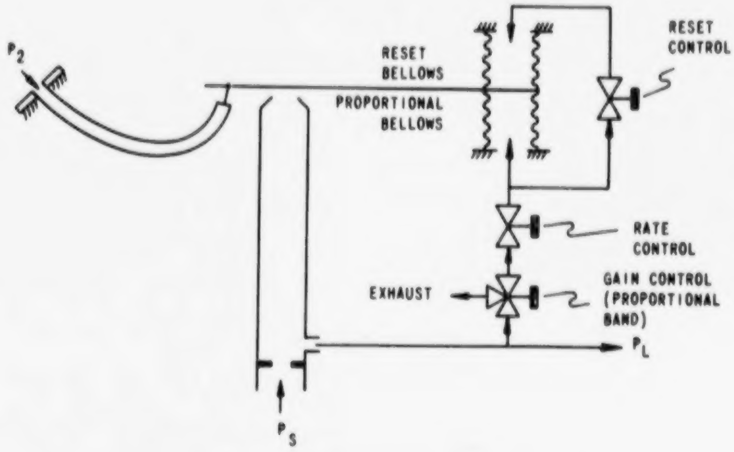
tive feedback. Since *negative feedback* decreases gain, *positive feedback* increases gain. This design is what makes a proportional plus reset controller work. When a disturbance first occurs and creates a transient condition, the reset restriction temporarily delays the positive feedback signal so that the negative feedback signal has time to cut the gain and maintain system stability.

As the transient condition decays and the system again approaches equilibrium, pressure from the proportional bellows bleeds through the reset valve to the reset bellows where the pressure slowly increases to cut the effect of the proportional bellows. When steady-state operation is finally returned, the pressures in the two bellows are again equal, cancelling their effect on each other, and the system is back to its previous high gain. Reset action in a controller is also called INTEGRAL because of mathematical relations in a process, so a proportional controller with rate adjust is called a PI controller.

Rate Control

One of the problems with a PI controller is that an input pressure change causes the proportional bellows to effect an immediate reduction in gain. The good effect of this rapid response is that the system usually remains stable. The bad effect of the rapid response is that transient control can almost get out of hand and cause poor or sluggish system performance. To improve transient control significantly, a RATE control valve is added to the controller. (Figure 5)

FIGURE 5



Courtesy Fisher Controls Company

This valve is designed to delay the gain cutting effect of the proportional action of the controller just long enough to permit the system itself to respond to the load change. However, the delay is not long enough for high gain to make the system unstable. Like the RESET valve, the RATE valve can be adjusted to just the right amount of delay, and once the pressure change has time to bleed across the rate valve restriction, the controller again acts as a PI controller. RATE is also referred to as DERIVATIVE, and a three-mode controller is called a PID controller.

HANDOUT #1

Conclusion

The three-mode or PID controller is a complex device designed around a simple flapper-nozzle amplifier which in turn is enhanced by other devices to take advantage of the basic principles of pressure and force. In fact, when tuning a controller a technician can slightly lift the flapper off the nozzle rather than temporarily changing setpoint; both procedures upset the system. An understanding of force-balance devices will help a technician develop good skills in controller tuning and in working with other force-balance control instruments.

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

HANDOUT #2 — CONVERTING PROCESS INFORMATION TO PERCENTAGES

Background

Technicians are often faced with the need to convert a variety of control information into a standard form such as percentage. Input information could be temperature in Fahrenheit or Celsius, gallons per minute or hour, psi, or level in inches or feet. A transmitter/transducer converts input signals to the psi or mA standard. Since many instrumentation measurements are based on a percentage of full scale, trying to compare a temperature input to a mA output would be like comparing apples and oranges. In other words, process information needs to be simplified by putting it into percentage so that two different measurements can be compared.

Making conversion to percentage

To illustrate how mA signal levels are converted to a percentage of full scale value, assume the following conditions:

1. A controller with a span of 4-20 mA has an output of 18 mA.
2. A process input change of 10% causes the controller output to go to 16 mA.

Suppose we wanted to calculate controller gain from the information given in out conditions. We have a scaling problem. Because the input change is expressed in percentage, the mA change must also be converted to percent. We can use a formula to accomplish the conversion:

$$\text{Controller Output} = \frac{\text{original output} - \text{new output}}{\text{span of output}}$$

$$\text{CO} = \frac{18-6}{20-4} = \frac{2}{16} = 12.5\%$$

Since 12.5% is the percentage of change from setpoint, we simply divide 12.5% by 10 (the 10% change in input) to calculate gain:

$$\text{Gain} = \frac{\text{controller output change}}{\text{controller input change}}$$

$$\text{Gain} = \frac{12.5\% \text{ output change}}{10\% \text{ input change}}$$

$$\text{Gain} = 1.2$$

HANDOUT #2

Using gain to find proportional band

With the values from the previous example, the proportional band is easy to find, and here is the formula:

$$\text{Proportional Band} = \frac{1}{\text{Gain}} \times 100$$

$$\text{PB} = \frac{1}{1.2} \times 100 = 83.3\% \text{ PB}$$

Making a complex conversion to percentage

Frequently two or more measurements hav to be converted into percentage. Let's set up conditions where this happens:

1. The output range to a valve is 3-15 psi with a span of 12.
2. The input range of a temperature transmitter is 50-200° F with a span of 150° F.
3. For a change of .75 psi valve signal, the process change measurement is 15° F.

In this case, the input change and output change should be calculated separately, so let's start with the change in input temperature:

$$\% \text{ of change} = \frac{\text{input change}}{\text{input span}} \times 100$$

$$\% \text{ of change} = \frac{15^\circ \text{ F}}{150^\circ \text{ F}} \times 100 = 10\% \text{ change}$$

Now, for the output change:

$$\% \text{ of change} = \frac{.75 \text{ psi output change}}{12 \text{ psi output span}} \times 100 = 6.25\% \text{ change}$$

With input and output changes converted to percentage, we can use the figures to calculate gain by simply dividing the output change percentage by the input gain percentage:

$$\text{Gain} = \frac{\text{output change}}{\text{input change}}$$

$$\text{Gain} = \frac{6.25\%}{10\%}$$

$$\text{Gain} = .625$$

HANDOUT #2

Naturally, knowing gain provides us with ready access to the proportional band:

$$PB = \frac{1}{\text{Gain}} \times 100$$

$$PB = \frac{1}{.625} \times 100 = 160\%\ PB$$

Conclusion

Converting information to usable form is a job technicians must be able to accomplish. Practicing with the formulas required to convert information to percentage will give a technician a better command of the skills required to evaluate controller performance.

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

HANDOUT #3 — GAIN AND PROPORTIONAL BAND RELATIONSHIPS

Background

Proportional action is the most important parameter in many controller tuning problems, yet it is probably the simplest part of controller tuning. Controllers approach proportional action from two perspectives, proportional gain or proportional band. They are two names that mean the same thing although gain and proportional band have an inverse relationship. Knowing how to think of proportional controller action as a function of either gain or proportional band will assist a technician in being able to solve control problems with the variety of controllers that technicians routinely encounter.

Gain

Let's talk about gain first. Gain is defined as the ratio of output magnitude to a change in input magnitude. In practice this means that when there is a change in input, the controller will respond with a change in output adequate to compensate for the deviation. Correcting the deviation may require a large or small change depending on the specific characteristics of the process being controlled. The speed and degree to which a controller responds to a deviation is determined by the gain setting of the controller.

Calculating gain

If the process variable being controlled deviated by 10% from its setpoint, and the controller responded with a 10% output change, the controller would have a gain of 1. Let's put it in a formula and see how it works:

$$\text{Gain} = \frac{\text{output change}}{\text{input change}}$$

In out previous example, there was a 10% change in input correct by a 10% change in output:

$$\text{Gain} = \frac{10\%\ \text{output change}}{10\%\ \text{input change}} = 1$$

Because of the varying characteristics of control loops, sometimes it is necessary to have gains greater than 1 and sometimes less than 1. Let's assume an input change of 10% and an output change of 20%, the gain would be 2. Let's see what it looks like in formula:

$$\text{Gain} = \frac{20\%\ \text{output change}}{10\%\ \text{input change}} = 2$$

HANDOUT #3

Let's try one more and assume an input change of 10% and an output change of 5%. Suddenly we have a gain of less than 1.

$$\text{Gain} = \frac{5\%\ \text{output change}}{10\%\ \text{input change}} = .5$$

Proportional band

When we say that proportional band is the inverse of gain, it means that gain can be used to quickly calculate proportional band. This too has a formula:

$$\text{Proportional Band} = \frac{1}{\text{Gain}} \times 100$$

Proportional bandis always expressed as a percentage, so let's use our formula to calculate proportional band when gain is known. For gain let's use the final formula presented in the discusion of gain where a 10% input change resulted in a 5% output change to produce a gain of .5:

$$\text{Proportional Band} = \frac{1}{.5} \times 100 = 200\%$$

Let's take one more example of proportional band, assuming an input change of 20% and a controller response that produces a 20% output change. Since this gives us a gain of 1, the proporational band is 100%.

$$\text{Gain} = \frac{20\%\ \text{output change}}{20\%\ \text{input change}} = 1$$

$$\text{Proportional Band} = \frac{1}{\text{Gain}} \times 100 = \frac{1}{1} \times 100 = 100\%$$

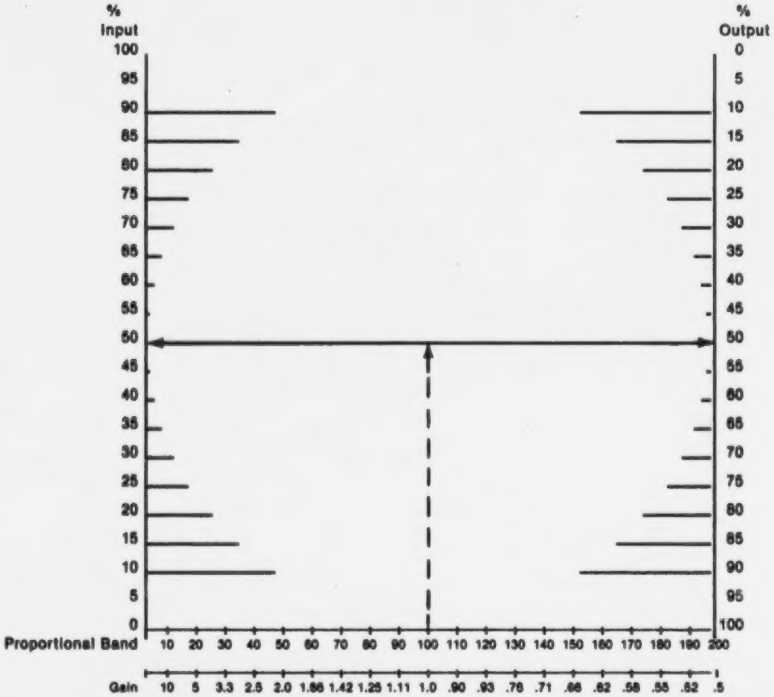
Dynamics of gain and proportional band

Refer to Figure 1 as you read the following.

The vertical column on the left of Figure 1 shows percentage of input. The vertical column on the right shows percentage of output. The horizontal scales at the bottom in Figure 1 show the inverse relationship of gain and proportional band. Across the center of Figure 1 is a vertical line connecting 50% input with 50% output. Later we will refer to this line as an axis. Think of this line as a teeter-totter that is resting on a fulcrum at its midpoint, which corresponds to a proportional band of 100% or a gain of 1.

HANDOUT #3

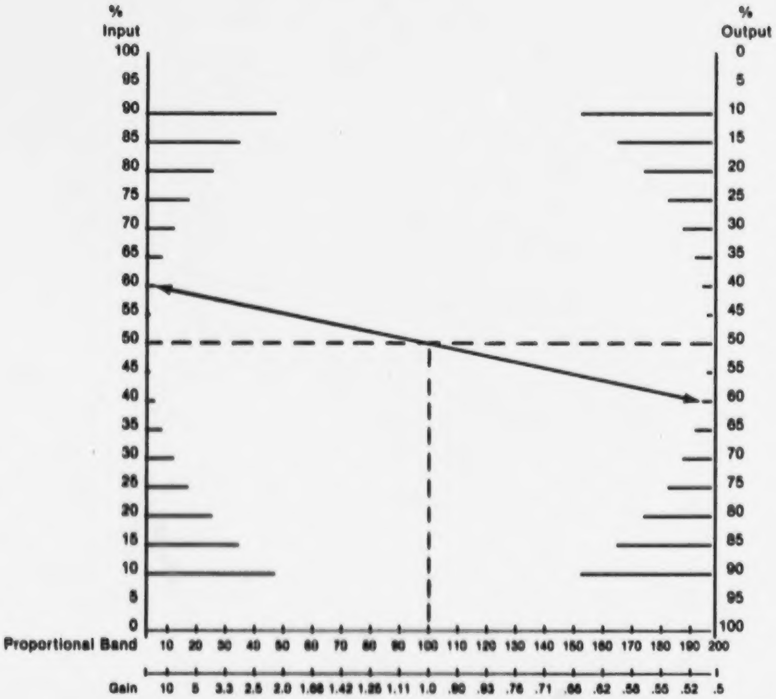
FIGURE 1


% Input
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
% Output
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Proportional Band
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Gain
10 5 3.3 2.5 2.0 1.66 1.42 1.25 1.11 1.0 .90 .93 .76 .71 .66 .62 .58 .55 .52 .5

To better demonstrate important relationships, assume that the percentage of input and the percentage of output in Figure 1 are both 50%, and the process being controlled is at a steady-state condition at 50%. Assume that an upset in the process produces a deviation of 10% from setpoint. Because of the gain of 1 (proportional band of 100%) the output percentage will got to 60% to compensate for the 10% increase in input. Look at Figure 2 for a moment.

HANDOUT #3

FIGURE 2



Since the output is still equal to the input, the proportional band remains at 100% and the gain remains at 1. What is happening is demonstrated in the following formula:

$$\text{Gain} = \frac{\text{output change}}{\text{input change}}$$

$$\text{Gain} = \frac{60\%\ \text{new output} - 50\%\ \text{original output}}{60\%\ \text{new input} - 50\%\ \text{original input}} =$$

$$\text{Gain} = \frac{10\%}{10\%} = 1$$

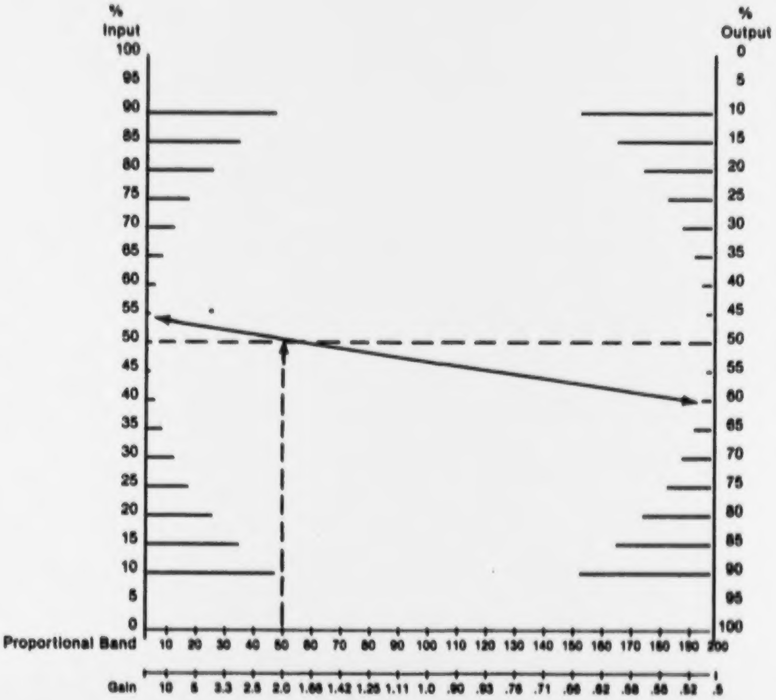
$$\text{PB} = \frac{1}{\text{Gain}} \times 100\ \frac{1}{1} = 100\%\ \text{PB}$$

Note in the formulas that the original input/output percentages have to be subtracted from the new input/output percentages to reflect the change. Remember that control systems are matched to a process and therefore have unique characteristics. This means that gain may sometimes be more than 1 or less than 1.

Let's examine Figure 3 to see what happens with an input increase from 50 to 55% with an increase in output percentage from 50 to 60%. Gain is now 2, and the proportional band is 50%.

HANDOUT #3

FIGURE 3



The formulas for calculting gain and proportional band remain the same, but the input/output percentages have changed. If we go back to our teeter-totter analogy, you can see the fulcrum has moved along the axis so that it is to the left directly above the gain and proportional band to indicate the tuning parameters for a particular process and its controller.

$$\text{Gain} = \frac{\text{output change}}{\text{input change}}$$

$$\text{Gain} = \frac{60\%\ \text{new output} - 50\%\ \text{original output}}{55\%\ \text{new input} - 50\%\ \text{original input}} =$$

$$\text{Gain} = \frac{10\%}{5\%} = 2$$

To convert to proportional band:

$$\text{Proportional Band} = \frac{1}{\text{Gain}} \times 100$$

$$\text{PB} = \frac{1}{2} \times 100 = 50\%\ \text{PB}$$

HANDOUT #3

Conclusion

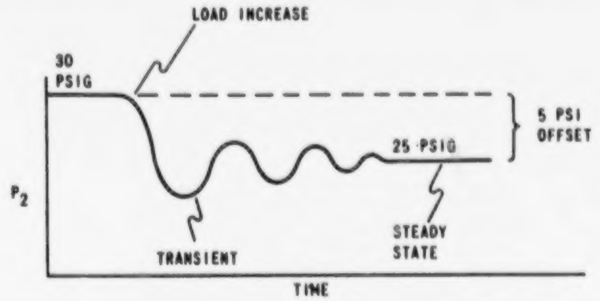
The graphs used in this handout were designed for demonstration and may not give exact measurements because of linearity problems that occur as percentages increase. However, the graphs demonstrate well the relationship of gain and proportional band as a controller responds to input changes. Working with controllers and tuning controllers requires that a technician have a good command of gain/proportional band relationships.

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

ASSIGNMENT SHEET #1 — EVALUATE CONTROLLER PERFORMANCE

Directions: The following illustrations depict controller responses to a disturbance as they might actually appear on a recorder. Examine the illustrations and answer the questions that follow.

FIGURE 1



Courtesy Fisher Controls Company

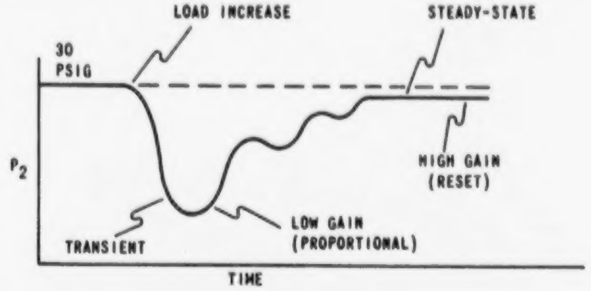
1. What kind of controller is probably being used in the control loop performance depicted in Figure 1?

   Answer: ______________________________

2. What is the original setpoint for the process in Figure 1?

   Answer: ______________________________

FIGURE 2



Courtesy Fisher Controls Company

3. What kind of controller is probably being used in the control loop performance depicted in Figure 2?

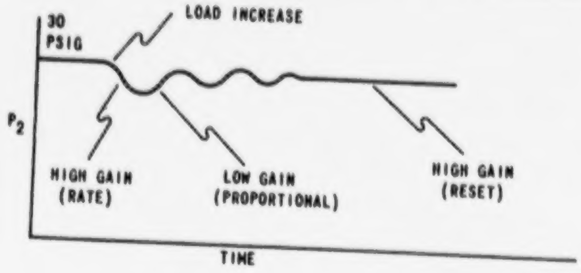
   Answer: ______________________________

ASSIGNMENT SHEET #1

4. The period immediately after a disturbance creates what condition in a process?

Answer: ____

FIGURE 3



Courtesy Fisher Controls Company

5. What kind of controller is probably being used in the control loop performance depicted in Figure 3?

Answer: ____

6. Justify your answer to question E.

Justification: ____

____

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

ANSWERS TO ASSIGNMENT SHEET

Assignment Sheet #1

1. A P (proportional) controller
2. 30 psig
3. A PI (proportional-integral) controller
4. A transient condition
5. A PID (proportional-integral-derivative) controller
6. Good control of the transient condition indicates a PID controller

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

JOB SHEET #1 — TUNE AN ELECTRONIC CONTROLLER IN AN AIR-FLOW CONTROL LOOP

A. Tools and materials

1. Foxboro 823 d/p transmitter, 0-100 in H_2O range
2. Moore 350 controller
3. Moore 362 3-pin recorder, 1-4 vdc inputs
4. Taylor I/P transducer
5. Badger control valve
6. Parker 1/4" NPT needle valve
7. Dwyer rotometer (sized according to flow)
8. Resistor, 1-5 volt drop for recorder (250 Ω)
9. Pennwalt electro-pneumatic calibrator
10. Magnahelic d/p pressure gauge 0-100 in H_2O
11. Hoses and connectors/fittings
12. Basic hand tools
13. Stopwatch
14. Calculator
15. Pencil
16. Safety glasses

Instrumentation recommended in this job sheet is designed to effect the best results from the procedure and does not reflect an endorsement of product. Instruments equal in performance may be substituted.

JOB SHEET #1

B. Routine #1 — Setting up the pneumatic loop

(NOTE: All control loops have individual characteristics, and the tuning procedure described in this job sheet will vary with equipment selection.)

1. Read the Pneumatic Loop Setup Data that accompanies this job sheet.
2. Review the pneumatic loop schematic in Figure 1 that accompanies this job sheet.
3. Compare the setup data and loop schematic so you will have a better idea of how your test instruments, loops, and procedures are related.

   ☐ Have your instructor check your progress.

C. Routine #2 — Calibrating test instruments

1. Put on safety glasses.
2. Calibrate the Foxboro 823 d/p transmitter for 0-80 in H_2O according to manufacturer's calibration procedures.

   ☐ Have your instructor check your calibration.

3. Calibrate the Taylor I/P transducer for a 3 to 15 psi output with a 4 to 20 mA input.

   ☐ Have your instructor check your calibration.

4. Calibrate the Moore 362 recorder for 1-5 volt inputs with a 0 to 100% indication.

   ☐ Have your instructor check your calibration.

D. Routine #3 — Assembling the pneumatic test loop

1. Put on safety glasses.
2. Assemble the flow loop as shown n Figure 1 which you reviewed before starting tuning procedures.

   ☐ Have your instructor check your loop assembly.

3. Connect bench supply air to the electro-pneumatic calibrator.
4. Make sure P1 and P2 on the calibrator are turned fully counterclockwise so they have no pressure.
5. Turn on bench supply air and slowly adjust P2 for 22 psi.

JOB SHEET #1

6. Set the 350 controller for MANUAL mode.

7. Connect the controller to a 117 vac power supply.

8. Use the manual valve on the controller to open and close the control valve to check for proper operation.

9. Leave the controller in manual mode and manually open the control valve for 100% output.

10. Adjust the needle valve for 100% flow to equal 80 in H_2O d/p.

    (NOTE: The best way to accomplish Step 10 is to alternately adjust the #1 regulator on the electro-pneumatic calibrator and the needle valve shown as FE on your schematic.)

11. Record the following 100% flow readings:

    a. Electro-pneumatic: ____________ psig

    b. Magnahelic gauge: ____________ psig

    c. Dwyer rotometer: ____________ scfm scfh (circle one)

13. Mark the settings on recorder paper.

    ☐ Have your instructor check your settings.

E. Routine #4 — Tuning the controller

1. Put on safety glasses.

2. Set the controller to MANUAL mode, and setpoint for 50% flow.

3. Set the reset and derivative adjustments to minimum.

   (NOTE: The derivative adjustment will not be set in this procedure.)

4. Set the proportional gain adjustment to maximum.

5. Set the controller automatic-manual switch to automatic.

6. Create a disturbance in the loop by increasing setpoint approximately 5%.

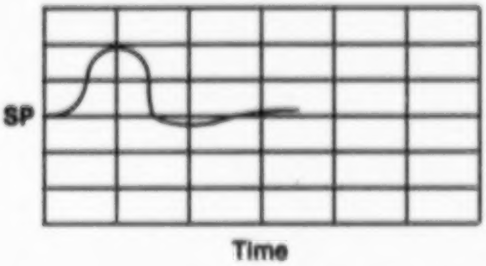
7. Return the loop to its original setpoint once the loop has responded to the disturbance.

8. Observe the response of the controller output pen, and note if the response quickly dampens out as it should.

JOB SHEET #1

9. Compare the response with the typical response shown in Figure 2, and consult with your instructor if the response is noticeably different.

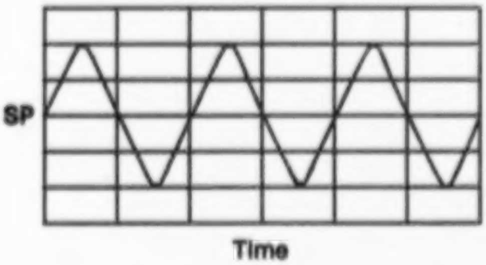
FIGURE 2



10. Reduce the proportional band by 50%, disturb the loop again, and decrease proportional band until sustained oscillation occurs.

11. Compare the sustained oscillation response with the typical response shown in Figure 3, and consult with your instructor if the response is noticeably different.

FIGURE 3



12. Watch for oscillations to increase in amplitude, and if they do, INCREASE the proportional band setting until even, sustained oscillation occurs.

13. Record the proportional band setting: ____________ % PB. This setting = ultimate proportional band.

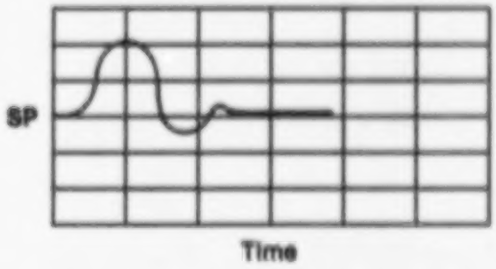
14. Complete the Ziegler-Nichols ultimate proportional band calculation: Proportional band setting = Ultimate proportional band × 2 (PB = UPB × 2). Record the new proportional band setting here: ____________ % PB.

15. Set the proportional band at the new setting and observe the reaction curve on the recorder.

JOB SHEET #1

16. Compare the reaction curve with that shown in Figure 4, and consult with your instructor if the response is noticeably different.

FIGURE 4

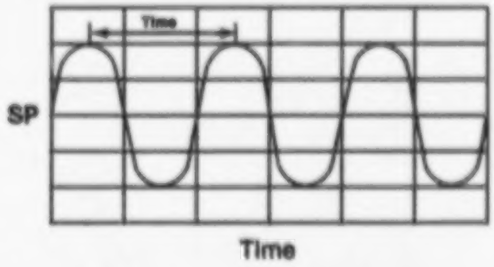


17. Readjust the proportional band to the ultimate proportional band setting obtained in Step 13 to enable proper tuning of the RESET (integral) control.

(NOTE: The response speed of the system set up for this procedure is extremely fast. If you have a problem with timing between the peaks, ask your instructor for help.)

18. Determine the ultimate period (UP) by calculating the time period between the peaks of the UPB curve as demonstrated in Figure 5.

FIGURE 5



19. Time the UP period with a stopwatch, and record the time here: ____________seconds; this is the new UPB figure.

20. Recalculate the proportional band setting which will change to some degree because of the affect the reset action will have on proportional band control.

21. Recalculate the proportional band using PB = UPB × 2.2.

22. Record the new PB setting here ____________ % PB.

JOB SHEET #1

23. Calculate the reset setting according to the following:

$$\text{Reset} = \frac{\text{Ultimate Period}}{1.2} \times (\text{Reset Time})$$

24. Record the reset setting here: ____________ .

25. Set the proportional band and reset adjustments to their new settings and observe the reaction curve on the recorder.

    ☐ Have your instructor evaluate your completed tuning procedure.

27. Clean up area and return tools and materials to proper storage.

JOB SHEET #1

Pneumatic Loop Setup Data

The pneumatic loop in the Figure 1 schematic controls air flow by using a needle valve (FE) that restricts air flow like an orifice. The non-linear differential pressure that develops across the needle valve becomes the input of the flow transmitter.

The 4-10 mA output circuit of the flow transmitter is in series with the 24-volt power supply and mA indicator of the electro-pneumatic calibrator, and the input of the Moore 350 controller. The controller will provide setpoint for the flow loop and also provide a square root function to linearize the signal. A 240-ohm resistor is across the controller's input. The voltage drop across the resistor will provide an indication and record of the non-linear input signal from the transmitter.

The recorder also receives a controller setpoint signal and a controller output signal.

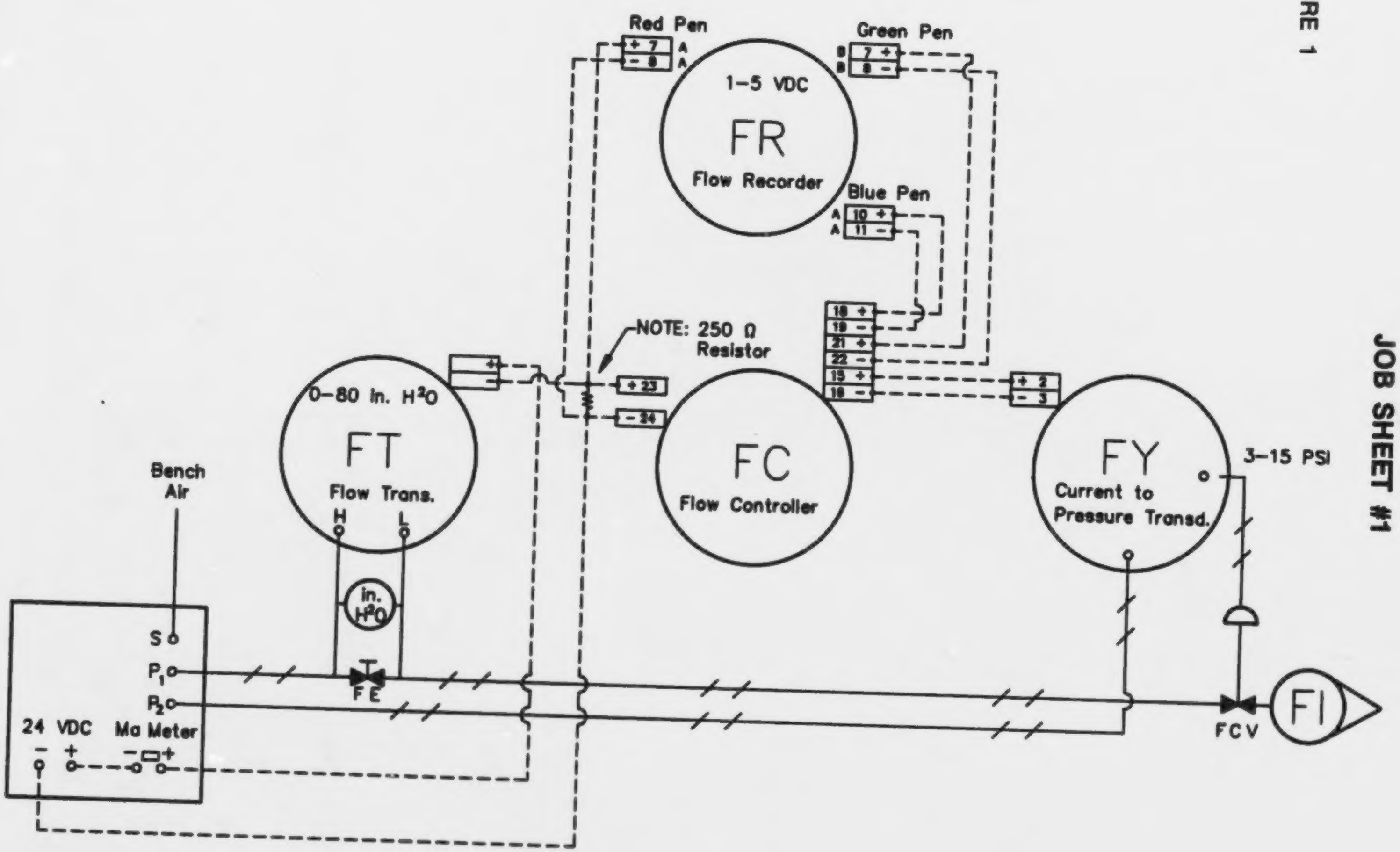
The 4-20 mA output signal of the controller is in series with the input of the current to pressure (I/P) transducer. The 3-15 psi output of the I/P transducer operates the pneumatic actuator of the control valve. Upsets may be created by increasing or decreasing the regulator pressure (P1) on the electro-pneumatic calibrator. An upset can also be caused by changing the controller setpoint.

Take care that the needle valve (FE) is NEVER 100% closed. This would prevent flow and exceed the differential pressure of the d/p transmitter and the d/p indicator.

The loop will be tuned using the Ziegler-Nichols ultimate proportional band and ultimate period methods to tune the proportional band and reset. In tuning the loop, derivative action is not required, and derivative will not be tuned.

JOB SHEET #1

FIGURE 1


Red Pen
+ 7 A
- 8 A
Green Pen
B 7 +
B 8 -
1-5 VDC
FR
Flow Recorder
Blue Pen
A 10 +
A 11 -
18 +
19 -
21 +
22 -
15 +
16 -
NOTE: 250 Ω Resistor
+ 23
- 24
0-80 in. H^2O
FT
Flow Trans.
H
L
FC
Flow Controller
+ 2
- 3
FY
Current to Pressure Transd.
3-15 PSI
Bench Air
S
P_1
P_2
24 VDC
- +
Ma Meter
- +
in. H^2O
F E
FCV
FI

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

PRACTICAL TEST #1
JOB SHEET #1 — TUNE AN ELECTRONIC CONTROLLER IN AN AIR-FLOW CONTROL LOOP

Student's name ______________________ **Date** ____________

Evaluator's name ______________________ **Attempt no.** ______

Student Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:		YES	NO
1. Set up the pneumatic loop properly.	1.	☐	☐
2. Calibrated test instruments properly.	2.	☐	☐
3. Assembled the pneumatic test loop properly.	3.	☐	☐
4. Recorded flow readings accurately.	4.	☐	☐
5. Tuned the controller with proper steps.	5.	☐	☐
6. Calculated new UPB and new PB.	6.	☐	☐
7. Calculated proper reset setting.	7.	☐	☐
8. Returned equipment and materials to proper storage.	8.	☐	☐

Evaluator's comments: ____

____

____

JOB SHEET #1 PRACTICAL TEST

PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

Criteria:				
Instrument Calibrations	Excellent 4	Good 3	Fair 2	Poor 1
Pneumatic Loop Setup	Proper 4	Acceptable 3	Fair 2	Unacceptable 1
Tuning Procedure	Well followed 4	Acceptable 3	Fair 2	Unacceptable 1
Controller Tuning	Well accomplished 4	Acceptably accomplished 3	Poorly accomplished 2	Unacceptable 1

EVALUATOR'S COMMENTS: ____

____

PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

TEST

NAME ____ SCORE ________________

1. Match the terms on the right with their correct definitions.

_____a. A device which operates automatically to regulate a controlled variable by adjusting the gain of a control loop to fit system dynamics

_____b. A method by which oscillation in a control loop is reduced or suppressed

_____c. The range of an input change required to activate a response from a control device

_____d. The degree to which a system exceeds or drops below setpoint after a disturbance

_____e. Generally the sensitivity of an element to changes in its input, and specifically, the ratio of output magnitude to a change in input magnitude

_____f. A period after a disturbance when rapid, high frequency signals enter a process

_____g. An operating condition that exhibits minimal change over an extended period of operation

_____h. The tendency of a process to fluctuate back and forth and remain unstable in response to high gain or too high a gain in a control loop

_____i. A control mode that produces a change in output proportional to a change in input

_____j. A control mode that moves a process back to or close to setpoint after a disturbance; also called reset

1. Oscillation
2. D
3. Transient condition
4. PID controller
5. Controller
6. Dead band
7. I
8. Deviation
9. Damping
10. P
11. Gain
12. Steady-state

TEST

_____k. A control mode that anticipates a disturbance and responds rapidly to keep the error from increasing; also called rate

_____l. A controller which has proportional, integral, and derivative control modes integrated into a single unit

2. Select true statements concerning open loop control by placing an "X" beside each statement that is true.

(NOTE: For a statement to be true, all parts of the statement must be true.)

_____a. Open loop control is the most used type of process control.

_____b. Open loop means there is no direct measurement of the controlled variable, and therefore no feedback to help compensate for changes in system input.

_____c. On/off control strategies are open loop systems because some systems still require a person to monitor a gauge or level, and turn a valve on or off in response to a high or low level in a sight glass.

_____d. On/off control strategies more frequently place a control mechanism on the level or gauge output so that it will turn a valve on/off as system input requires.

_____e. On/off control strategies have brought significant changes to instrumentation:

1) Since technicians or operators were freed from having to monitor indicators, they could perform other duties.

2) Since the valve had to be turned on/off frequently, more technicians were hired to do the job.

_____f. Oscillation in the control valve is characteristic of on/off controls, and an adjustment called "dead band" is used to control oscillation.

_____g. Dead band is the amount of input required before a control device responds to the input.

_____h. Open loop on/off controls are not only subject to oscillation in the control valve, frequent load variations still require manual monitoring and manual adjustment of the loop, and automatic closed loop systems were developed to help solve these and other control problems.

TEST

3. Complete statements concerning closed loop control by circling the material that best completes each statement.

   a. Closed loop control means that a control system has:

      1) A means to measure the (**controlled variable, input**) and generate feedback;

      2) A capability to compare the controlled variable measurement with (**setpoint, output**) to determine if there is a deviation;

      3) The means to provide a corrective adjustment to (**a source of supply, an actuator/control valve**) to compensate for the deviation.

   b. The capability of a controller to receive feedback information and compare that information with (**setpoint, output**) is the heart of all automatic closed loop control strategies.

4. Complete statements concerning gain and proportional band by circling the material that best completes each statement.

   a. In a control loop itself, the process receives an input and provides some kind of output; the ratio of the change in output magnitude to the change in input magnitude is known as (**GAIN, COMPENSATION**).

   b. The rule of thumb is: the (**lower, higher**) the gain, the greater the output change for a given input.

   c. Gain expresses the sensitivity of an element to changes in its input; this means that a device with (**high, low**) gain is very sensitive to input changes.

   d. Since the function of a controller is to compensate for (**loss of output, load changes**), this requires a GAIN adjustment, or a PROPORTIONAL BAND adjustment.

   e. The GAIN adjustment on a controller and the PROPORTIONAL BAND adjustment have an inverse relationship:

      1) (**Narrowing, Widening**) the proportional band is the same as increasing gain;

      2) (**Widening, Narrowing**) the proportional band is the same as decreasing gain.

   f. Since high gain promotes good control, it would seem that setting a controller on a high gain would solve all problems, but high gain can lead to another testy problem called (**instability, overflow**).

   g. Instability takes a system into excessive oscillation which can cause a control valve to (**keep moving up and down, completely open**).

TEST

h. To avoid instability, the gain can be lowered, but this produces (**sluggish system performance, increased costs**).

i. To have (**high, low**) gain for good performance at the risk of instability or to have (**low, high**) gain for poor performance with no risk of instability created the dilemma that controller designers have attempted to solve.

5. Select true statements concerning basic controller action by placing an "X" beside each statement that is true.

(NOTE: To be true, all parts of a statement must be true.)

_____a. There are three types of controller action:

1) P or proportional controller action produces a change in output in proportion to the change in input, the error, but P action will not always return a control loop to setpoint.

2) I or integral action moves a control loop back to or close to setpoint after an error and is also called RESET action. I action is combined with P action in the design of PI controllers.

3) D or derivative controller action anticipates an error and responds rapidly to prevent the error from becoming too large. Derivative action is also called RATE, and D action is combined with P and I action in the design of PID controllers.

_____b. Each controller action provides a particular response to an error or a change in input, and controller action can best be demonstrated by examining the P I functions in a two-mode PID controller.

6. Select true statements concerning proportional control by placing an "X" beside each statement that is true.

_____a. When a control loop experiences an abrupt full load upset, the pressure on the actuator diaphragm must decrease in order to allow the control valve to open and accommodate the increased flow.

_____b. The amount of pressure decrease required to fully open the control valve is called OFFSET.

_____c. Since the amount of OFFSET required to open the valve is proportional to the change in load, this type of control action is called PROPORTIONAL CONTROL.

_____d. One of the problems with proportional control is that an upset has a transient condition which results in extremely poor system performance.

TEST

_____e. Another problem with proportional control is that the offset must continue as long as the load continues at its new flow rate.

_____f. By adding a proportional controller to the system depicted in the example, the sensitivity of the system to an upset can be increased by increasing the gain on the controller.

_____g. Sensitivity means that the loading pressure required to fully open the valve is decreased greatly so that the transient condition of the upset is better controlled.

_____h. The high gain made possible by the proportional controller returns the system to a steady-state operation with minimal change in system performance, and the new steady-state operation will be much closer to the original setpoint.

_____i. It would seem that a proportional controller set to a high gain would provide ideal loop control, but high gain can cause a system to oscillate back and forth in an unstable manner.

7. Complete statements concerning integral control by circling the material that best completes each statement.

   a. An instability problem with a proportional controller can be solved by **(reducing, increasing)** the gain to broaden the proportional band, but the **(lower, higher)** gain results in a larger steady-state offset and less than desired performance.

   b. To avoid a large steady-state **(upset, offset)**, RESET action can be added to a controller.

   c. A proportional controller with RESET introduces a gain **(increase, reduction)** during the transient portion of a disturbance, and this prevents the system from oscillating in an unstable manner.

   d. After the proportional action in the controller manages to get the transient condition under control, the RESET action moves the controller back to a **(low, high)** gain condition where the steady-state offset is very close or back to original setpoint.

   e. RESET action is also referred to an INTEGRAL, and a controller with proportional and integral action is called a **(PI, PD)** controller.

   f. One important characteristic of PI control action is that in order to keep the system stable, the high gain of the controller has to be sacrificed during the **(transient, offset)** condition.

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g. With PI control action, the RESET signal has to be delayed just enough to match the recovery characteristics of the process under control:

   1) If gain increases too rapidly, the system will be (**unstable, sluggish**);

   2) If gain increases too slowly, the system will be (**sluggish, unstable**).

8. Complete statements concerning integral time and reset time by circling the material that best completes each statement.

   a. The rate at which a controller repeats corrective action required to (**reduce, contain**) offset requires integral action.

   b. The rate at which corrective integral action is repeated is expressed in two ways:

      1) Reset rate or (**repeats per minute, minutes per repeat**).

      2) Integral time or (**minutes per repeat, repeats per minute**).

   c. Reset rate and integral time have (**an inverse, a direct**) relationship similar to gain and proportional band.

   d. Integral action is required to bring a measured variable back to setpoint after an upset, and how often the corrective action is repeated is a function of (**reset rate or integral time, derivative action**).

   e. The integral time settings used in controller tuning should be related to the (**preset, response**) time of the loop being controlled.

   f. It is difficult to tune integral action without an estimate of the (**input, response time**) the loop requires.

   g. A (**constant cycle, drop in output**) in a loop is usually an indication of too short an integral time.

9. Complete statements concerning derivative control by circling the material that best completes each statement.

   a. In PI control, an upset is immediately answered with (**an increase, a reduction**) of controller gain so that the system will remain stable.

   b. Immediate (**reduction, inverse**) of controller gain means that transient control suffers, and the way to avoid rapid gain reduction is to add RATE action to a PI controller.

   c. Since RATE is also referred to as DERIVATIVE action, a controller with all three types of action is called a (**PID, PD**) controller.

TEST

d. The advantage of full (**PD, PID**) action is that the RATE action can delay the rapid gain reduction just long enough for the system to begin responding to the load disturbance, but not so long that the system becomes unstable.

e. In ideal PID control, a step change in the load is handled in the following sequence:

1) The RATE control momentarily (**raises, maintains**) the high gain to improve initial response to the transient condition;

2) The PROPRTIONAL control (**reduces, raises**) the gain during the major part of the transient condition to maintain stability;

3) As the system again approaches steady-state operation, the RESET control slowly increases the gain back to its (**high, low**) steady-state value; in other words, back to or close to setpoint.

10. Select true statements concerning dynamics of controller tuning by placing an "X" beside each statement that is true.

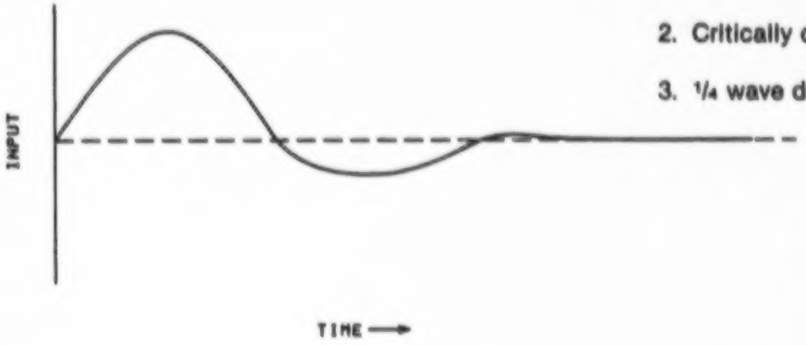
_____a. In every control loop there is a critical frequency where disturbances tend to reinforce themselves; when disturbances do occur, many loops have a tendency cycle at this frequency.

_____b. The point where a loop cycles in response to a disturbance is referred to as the system cycling frequency or the critical frequency.

_____c. A rule of thumb is that to keep a loop from becoming unstable, the loop gain must be sufficiently high at the critical frequency.

11. Identify damping profiles by inserting the proper identification number below each of the following damping profiles.

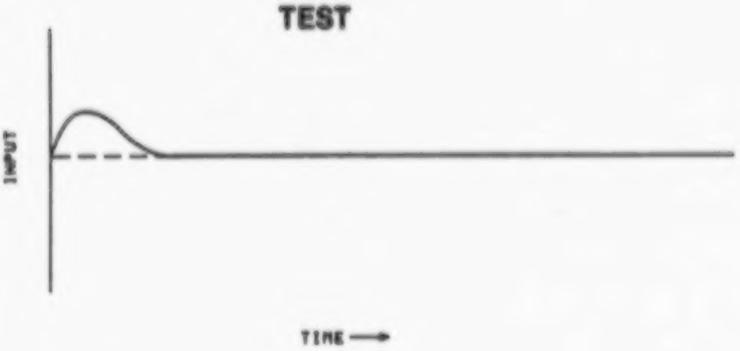
_____a.



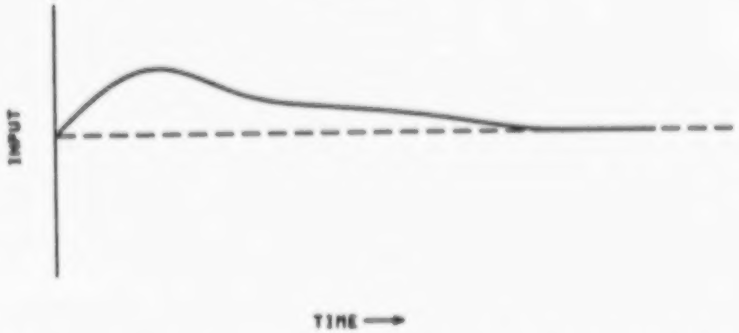
1. Overdamped
2. Critically damped
3. ¼ wave damping

TEST

______b.



______c.



12. Solve the following problems concerning controller applications by selecting the best answer.

    a. Because PID controllers have three-mode control they are what, perfect for all applications or generally restricted to critical temperature loops?

    Answer: ____________________

    b. The most commonly used controllers are what, the basic P controller or the PI controller?

    Answer: ____________________

13. Solve the following problems concerning controller tuning basics by selecting the best answer.

    a. To find the critical frequency of a system, what should you do, look it up in the records or look for it during the actual tuning process?

    Answer: ____________________

    b. Before starting controller tuning it is best to what, have records of past controller settings or record the current controller settings?

    Answer: ____________________

TEST

14. Solve the following problems concerning basic tuning for flow loops by selecting the best answer.

    a. For simple flow loops, the primary control action is usually what, integral or derivative?

       Answer: ______

    b. Tuning a simple flow loop should start by setting integral time at the appropriate setting, and setting gain at what, maximum or minimum?

       Answer: ______

    c. Part of simple flow loop tuning is to what, increase the gain by 50% every minute or reduce the gain by 50% every minute?

       Answer: ______

    d. After flow starts to oscillate what should the gain then be set to, ¼ to assure ¼ wave dampening or ½ the value at which the flow oscillated?

       Answer: ______

15. Solve the following problems concerning basic tuning for level loops by selecting the best answer.

    a. Is it true that in many level loops proportional action alone is sufficient and integral action may not be necessary, yes or no?

       Answer: ______

    b. One way to determine gain for a level loop is to base it on what, input alone or the error that can be tolerated?

       Answer: ______

    c. The gain calculation for level loops is based on the maximum change in valve position, and what else, the minimum change in output or the maximum change in level?

       Answer: ______

TEST

16. Complete statements concerning cascade control by circling the material that best completes each statement.

    a. In a normal cascade loop, there are two controllers, one called a **(primary, base)** and the other a **(secondary, field)**.

    b. The output from the **(secondary, field)** controller moves the control valve while the **(primary, base)** controller provides setpoint for the secondary controller.

    c. The real purpose of a cascaded loop is to **(minimize, eradicate)** disturbances or errors in a secondary loop, and is used when the desired control point such as temperature, is slow compared to the manipulated variable which is probably flow.

17. Solve the following problems concerning tuning cascade controllers by selecting the best answer.

    a. When tuning a cascaded loop, always start with which controller, the primary or the secondary?

       Answer: ____________________

    b. The integral time in a primary controller should be what, longer than the integral of the secondary or shorter than the integral of the secondary?

       Answer: ____________________

    c. When the integral time of a secondary controller is less than 1 minute, the loop should probably not be cascaded, but should two loops of similar speed be cascaded, yes or no?

       Answer: ____________________

18. Solve the following problems concerning tuning interactive controllers by selecting the best answer.

    a. In tuning interactive loops, what controller should be tuned first, the controller in the slowest loop or the most important controller?

       Answer: ____________________

    b. Another controller in a loop should be tuned in what way, so that it does not cause excessive cycling in the most important controller or so that it causes the most important controller to cycle only at critical frequency?

       Answer: ____________________

TEST

19. Complete statements concerning feed forward control by circling the material that best completes each statement.

    a. Feed forward is a control scheme that uses information about conditions that could upset a controlled variable, and takes corrective action to minimize upsets of the (**controlled variable, entire system**).

    b. Feed forward is different from other control schemes in that the scheme uses process information that could upset the controlled variable, but the scheme does not use information from the (**system, controlled variable**) itself.

    c. When a process is difficult to control with feedback loops, a feed forward scheme might be used, and in cases where (**input, quality**) control is critical, feed forward control can sometimes effect improved control.

    d. A feed forward control scheme is based on (**designs, equations**) that demand a in-depth knowledge of a process and its instrumentation, and technicians working with a feed forward scheme need advanced skills or the help of an engineer.

20. Select true statements concerning distributed control systems by placing an "X" beside each statement thatis true.

    ______a. To take advantage of the speed, communications capabilities, and the analytical power of computers, many process industries have installed main frame computers.

    ______b. As the name implies, a distributed control system has individual microcomputers distributed at important locations in a system with a host microcomputer to control the system.

    ______c. The distributed units communicate with each other and with the host computer over a data bus that forms a high-speed communications network.

    ______d. Distributed controls are attractive because of their speed and accuracy, and also because their modular design permits the location of all systems monitoring at various locations.

    ______e. CRT monitors in a distributed control console provide visual displays of total system functions so operators and technicians can evaluate performance and isolate trouble spots almost instantly.

    ______f. Distributed control systems are interfaced with printers to provide automatic printing of selected data at the end of intervals ranging from one minute to many hours or end-of-period logs such as the end of a shift, day, week, or month.

    ______g. Distributed control systems constantly exchange process information for updating and evaluation, which makes them more reliable than controller-based systems.

    ______h. An instrumentation technician working in an installation with distributed controls should make it a point to learn the system and appreciate the assistance it provides for evaluation and troubleshooting.

TEST

21. Complete statements concerning programmable logic controllers by circling the material that best completes each statement.

    a. Programmable logic controllers are basically **(analog computers, microcomputers)** usually dedicated to discreet sequential functions such as starting or stopping motors or activating solenoids.

    b. Recent PLC designs incorporate **(both discreet and analog, advanced analog)** functions for a combination of power and speed that makes them attractive alternatives to other control devices.

    c. The capability of **(analog, discreet)** functions has expanded PLC application potential to the point they are replacing proportional and integral functions in controllers.

    d. PLCs not only function as **(motor starters, controllers)**, they can be effectively integrated with various measuring and control instruments and promise to earn a prominent place in process instrumentation.

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

22. Evaluate controller performance. (Assignment Sheet #1)

23. Demonstrate the ability to tune an electronic controller in an air-flow control loop. (Job Sheet #1)

CONTROLLERS AND CONTROLLER TUNING
UNIT VI

ANSWERS TO TEST

1.

a.	5	e.	11	i.	10
b.	9	f.	3	j.	7
c.	6	g.	12	k.	2
d.	8	h.	1	l.	4

2. b, c, d, f, g, h

3. a. 1) Controlled variable
      2) Setpoint
      3) An actuator/control valve
   b. Setpoint

4. a. GAIN
   b. Higher
   c. Low
   d. Load changes
   e. 1) Narrowing
      2) Widening
   f. Instability
   g. Keep moving up and down
   h. Sluggish system performance
   i. High, low

5. a

6. a, b, c, d, e, f, g, h, i

7. a. Reducing, lower
   b. Offset
   c. Reducation
   d. High
   e. PI
   f. Transient
   g. 1) unstable
      2) Sluggish

ANSWERS TO TEST

8. a. Reduce
   b. 1) Repeats per minute
      2) Minutes per repeat
   c. An inverse
   d. Reset rate or integral time
   e. Response
   f. Response time
   g. Constant cycle

9. a. A reduction
   b. Reduction
   c. PID
   d. PID
   e. 1) Maintains
      2) Reduces
      3) High

10. a, b

11. a. 3
    b. 2
    c. 1

12. a. Generally restricted to critical temperature loops
    b. The PI controller

13. a. Look for it during the actual tuning process
    b. Record the current controller settings

14. a. Integral
    b. Minimum
    c. Increase the gain by 50% every minute
    d. ½ the value at which the flow oscillated

15. a. Yes
    b. The error that can be tolerated
    c. The maximum change in level

16. a. Primary, secondary
    b. Secondary, primary
    c. Minimize

ANSWERS TO TEST

17. a. The secondary
    b. Longer than the integral time of the secondary
    c. No

18. a. The most important controller
    b. So that it does not cause excessive cycling in the most important controller

19. a. Controlled variable
    b. Controlled variable
    c. Quality
    d. Equations

20. b, c, e, f, g, h

21. a. Microcomputers
    b. Both discreet and analog
    c. Analog
    d. Controllers

22. Evaluated to the satisfaction of the instructor

23. Evaluated according to criteria in Practical Test #1

INTERACTIVE LOOPS: BOILERS

UNIT VII

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss the principles of interaction, and the ways cascade control strategies are used in interactive loops. The student should also be able to relate boiler control devices to their applications, and identify control functions in interactive boiler loops. These competencies will be evidenced by correctly completing the procedures outlined in the assignment sheet, and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to interactive loops: boilers with their correct definitions.
2. Select true statements concerning principles of interaction.
3. Complete statements concerning oil combustion control systems.
4. Complete statements concerning gas and coal combustion control systems.
5. Solve problems concerning EPA guidelines for exhaust flue gases.
6. Select true statements concerning furnace pressure control.
7. Solve problems concerning steam drum control.
8. Complete statements concerning steam temperature control.
9. Solve problems concerning loop isolation for maintenance.
10. Arrange in order the steps in a blow down procedure.
11. Solve problems concerning return to normal operation.
12. Identify control functions in interactive boiler loops. (Assignment Sheet #1)

INTERACTIVE LOOPS: BOILERS
UNIT VII

SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information and assignment sheets.

C. Discuss unit and specific objectives.

D. Discuss information sheet.

E. Use Handout #1 to reinforce materials in the information sheet, but have available other P&IDs to show students examples of other control systems with interactive loops.

F. Invite a supervisor or operator from a local or area industry that uses boilers in their production process to talk to the class about boiler controls and the elements of safety required for boiler control schemes.

G. Give test

REFERENCES USED IN DEVELOPING THIS UNIT

A. Hall, Ronald P. *Automated Process Control Systems (Concepts and Hardware).* Englewood Cliffs, NJ: Prentice-Hall Book Co., 1981.

B. Johnson, Curtis D. *Process Control Instrumentation Technology*. New York, NY: John Wiley & Sons, 1982.

C. Liptak, Bela G. *Instrumentation Processing in the Industries*. Philadelphia, PA: Chilton Book Company, 1973.

D. Potvin, John. *Applied Process Control Instrumentation*. Reston, VA: Reston Publishing Co., 1983.

E. Tyson, Forrest. *Industrial Instrumentation*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1980.

INTERACTIVE LOOPS: BOILERS
UNIT VII

INFORMATION SHEET

I. **Terms and definitions**

A. Bias — The addition or subtraction of a percentage of a signal into or out of a controller

B. Blow down — A maintenance procedure that clears the impulse lines that run from an orifice plate to a transmitter

C. Boiler — A tank-like device that uses a furnace, heat exchanger, and steam drum to turn water into steam for use in industrial plant operations

D. Bounce — Any sudden upset in a process

E. Bumpless — A smooth transition from automatic to manual or manual to automatic operation

F. Cascade — A control strategy that uses controllers in series, one after the other, to improve control output

G. Combustion — The rapid burning of oxygen and fuel to produce heat

H. Damping — The restriction of an oscillating signal so that it increases or decreases more slowly

I. Draft — The gas flow through a furnace created by the expansion of gases, and the action of lighter gas going up a furnace stack

J. Interactive control — A form of control necessary in complex plan operations where the controller action in one loop produces an outcome that influences another loop

K. Opacity — The measurement of reflected light used to determine the percentage of particulate matter such as smoke and soot in exhausted flue gases

L. Ramping — A condition where a controller will exceed the 100% signal above the 15 psi standard or below the 3 psi standard

M. Solid fuels — Materials such as coal and wood that are burned in a furnace, and must be handled mechanically

N. Superheated steam — Water that is turned into steam in the steam drum of a furnace, and then reheated to add more heat energy before it goes to run a load

INFORMATION SHEET

II. Principles of interaction

A. Industrial process control is seldom accomplished with individual loops that control a single parameter; rather, processes are normally comprised of multiple loops interacting to control some large process.

B. In many process controls, the interaction of loops is created by using the output from a loop which is measuring one variable to provide the setpoint for another loop that is working on another variable.

C. One effective interaction control strategy is cascading control where two levels of control are very common.

D. Cascading more than two levels of control can create several problems such as cascading the gains, noise multiplication, and delays in action on some process variable.

E. Interaction between loops in a large process is unavoidable, and since the product is normally acted on by all the loops in a control system, interaction is part of system design, and therefore desirable.

F. Since the boiler system is one of the most commonly used systems in process industries, boiler sub-systems provide excellent examples of principles of interaction.

III. Oil combustion control systems

A. Combustion control systems in boilers control the burning of fuel to produce heat that converts water into steam.

B. Since oil, gas, and coal are all commonly used boiler fuels, each fuel type requires a separate type of combustion control.

C. In oil combustion control, the general requirements are the presence of air and some material that can rapidly combine with the oxygen in the air to form heat.

D. In oil, gas, and coal, the materials that combine with oxygen are hydrogen, carbon, and traces of other materials such as sulfur.

INFORMATION SHEET

E. To achieve efficient combustion, an oil combustion system must control:

1. The flow of oil into the combustion chamber.

2. The flow of air into the combustion chamber.

3. Gases from the stack.

4. Pressure inside the furnace.

F. An oil combustion control system must continuously balance the heat input with the demand for heat to produce steam while using the minimum amount of fuel and air.

G. Another equally important objective of combustion control is to keep the furnace in its safe operating zone while producing steam.

IV. Gas and coal combustion control systems

A. Gas combustion systems parallel oil combustion systems for the most part, but there are two major differences.

B. First, gas can be compressed, and fuel pressure is an important element.

C. Second, the BTU value of gas is much higher than oil, and this becomes a control consideration.

EXAMPLE: No. 6 oil has a BTU rating of 18,640 BTUs/lb while natural gas is rated at 23,850 BTUs/lb.)

D. Coal and oil combustion systems parallel each other for the most part, except that coal is a solid which requires mechanical loading.

E. With coal combustion, the size of coal pieces, density, and thickness become important as well as control of the velocity of air passing over or through the coal to support combustion.

V. EPA guidelines for exhausted flue gases

A. The EPA (Environmental Protection Agency) has issued guidelines to help control detrimental particulate matter from being exhausted into the atmosphere.

B. One popular method of monitoring exhausted flue gases is to measure the opacity of exhausted flue gases.

C. Opacity monitoring is accomplished by directing a light across the flue to a mirror and measuring the amount of light reflected back to the source.

INFORMATION SHEET

D. Opacity is measured in percentage ranging from 100% when no light is reflected back to 0% when all light is reflected back.

E. Gas, coal, and oil combustion systems must all meet EPA standards.

VI. **Furnace pressure control**

A. Pressure inside the furnace of a boiler is important to the production of the heat required to produce steam.

B. Pressure is controlled by measuring the inputs such as fuel and air, and the outputs such as leakage, flue gas, and entrained solids like ash, reaction gases, and byproducts that leave with the flue gas.

C. Because of thermal expansion and combustion reaction, the volume of gas leaving a furnace is much greater than the volume of gas entering, so the real control problem is that of balancing mass in with mass out.

D. The draft that causes the pressure difference may be a natural draft caused by gas moving out of the furnace and up the stack, or it may be induced or forced by fans.

E. Induced draft refers to pulling the gases out of the stack end of the furnace by fan.

F. Forced draft refers to forcing air into the front end of the system by fan.

G. Because the furnace pressure is small, 1 to 3 inches of water, the pressure is measured by a special draft gauge, and transmitted to the controller which in turn controls a final element that is either a fan control for induced or forced draft, or a damper near the stack if it is a natural draft furnace.

VII. **Steam drum control**

A. The steam drum is located at or neat the top of the furnace, and is a large-area drum that allows steam to separate from the water as heat is applied.

B. It is important for the steam drum to provide a large volume of water, and a large area for separation of steam.

C. The control task at the steam drum is to provide a balance of replacement water for mass lost to steam production, inputting a pound of water for every pound of steam sent to the load.

D. The control problem is critical in that the level in the drum must be held very close, because if level gets too high, water solids will get into the steam and cause damage to steam-operated equipment, and if level gets too low, boiler tubes will heat up and warp. A really low level condition can cause tubes to rupture.

INFORMATION SHEET

VIII. **Steam temperature control**

A. In systems that require superheated steam, the superheaters are normally special alloy heat exchangers arranged in stages that follow the output from the steam drum.

B. Temperature of the steam must be controlled in order to produce the proper superheated steam temperature of approximately 850°F, but not damage the special alloy heat exchangers.

C. Control is achieved with thermocouple measurement at the output of the steam, and this controls a water injection system between the superheaters to give the correct temperature.

IX. **Loop isolation for maintenance**

A. Since interactive loops affect each other, and therefore an entire process, an interactive loop cannot be shut down for maintenance or repair without causing a problem with the loops around it.

B. In order to remove a loop from an interactive process, the entire system must be examined to determine what affect removing the loop would have on the system.

C. Once the extent of interaction is determined, a plan must be formulated to remove the loop without shutting down the total process, if at all possible.

D. Some loops are so critical that the entire process must be shut down to service them.

E. Normally, a process can continue to operate during maintenance while the questionable loop is removed by placing it into a manual control mode.

F. With a loop in manual control mode, an operator can control the process to compensate for the lack of that part of the system during maintenance.

X. **Steps in a blow down procedure**

A. Since meters on a steam flow line should be below the orifice plate, the impulse lines from the orifice plate to the transmitter may plug up and have to be cleared.

B. A blow down procedure is used to clear impulse lines:

1. Open the impulse lines with appropriate safety precautions.
2. Permit water to blow out of the lines until steam appears.
3. Permit the steam to blow momentarily, then shut it off.

INFORMATION SHEET

4. Reconnect the impulse lines.

5. Turn steam on again and allow enough time for it to condense back to water so the transmitter will give a proper reading.

XI. **Return to normal operations**

A. Restoring automatic operations to a process that has been down to maintenance requires reversing the procedure for bringing the loop out of service.

B. First, the loop is brought on line manually, and the interactive loops operating around it are switched to automatic in some critical order.

C. Next, the newly serviced loop is placed on line in the proper order, and switched to automatic mode.

(CAUTION: Bringing a loop back to normal operations requires careful attention to procedures, and articulate communications between technicians completing the work and the operator who puts the loop back into operation)

INTERACTIVE LOOPS: BOILERS
UNIT VII

HANDOUT #1 — STEAM DRUM CONTROLS

Purpose

Boiler controls present special design problems that employ a variety of control schemes. Examining the details of steam drum controls in a boiler control scheme will help expand one's appreciation for the interaction of devices in complex control schemes, and provide a better understanding of how the controls are managed to assure fast, safe maintenance. The process examined in this handout is a boiler control scheme faced with a two-fold problem: first, to produce high pressure steam for use in power generation, and second, to control plant fuel gas pressure. The scheme has only three boilers; however, any number of boilers can be added because the instrumentation for all boilers is the same. Consult the diagrams indicated in the sections that follow.

Three-element drum level control

Refer to Diagram 1 that accompanies this handout.

The flow of water to a boiler is controlled by three things: steam flow, water flow, and drum level. The steam flow (FT1) and water flow (FT2) transmitters send their output signals through square root extractors to a summing relay (FY1) located behind the control board. The steam flow signal is sent to the negative input of the summer, and the water flow signal is sent to the positive summer input. As long as both negative/positive inputs are the same, the output will remain at 50%. The output of the summer is the measured variable sent to one of the flow controllers (FC-604, FC-620, or FC-565). When the signal is below setpoint, the controller will open the control valve and increase the flow of water until the water flow signal arriving at the positive input of the summer is the same as the steam flow input, and the summer output returns to 50%.

The level transmitter (LT1) sends its output signal through an inverse derivative relay (LY1) to the measured variable input of the level controller (LC1). The purpose of the derivative relay is to dampen out the sudden changes in level caused by the shrinking and swelling of liquid in the drum.

This control scheme is used on three boilers, and the instrumentation is repeated. That is why the 3-element drum controller and the flow controller have three numbers, 604, 620, and 656 — one for each boiler. The output from the level controller provides the setpoint for one of the flow controllers, FC0604, FC-620, and FC-656.

HANDOUT # 1

In automatic mode, the output of LK1 provides the setpoint for the level controller. In manual mode, the LK1 sends a 20 psi signal to the clippard valve, opening the valve which causes the setpoint signal and the measurement signal sent to the flow controller to be the same. This signal is applied to the flow controller and the level controller to lock their outputs at the same value as the LIK output. The LIK output then controls the feed water valve manually. To switch operational modes from AUTO to MANUAL to AUTO, simply move the transfer lever. The transfer is bumpless. To conserve space, the flow and level controllers are mounted behind the board. In this control scheme, instead of having a board panel for each of the controllers, the only board panel is for the LIK AUTO-MANUAL station.

Fuel control system

Refer to Diagram 2 that accompanies this handout.

The fuel gas flow (FT) of fuel gas pressure (PT) transmitters at the top of Diagram 2 send their outputs to a computer (FY1) which corrects the fuel gas flow signal for changes in pressure at the burners. This is required because changing the pressure changes the orifice calculations and they must be corrected. The orifice is located downstream of the fuel gas control valve, which is the reason for the pressure compensation. The output of the pressure correction computer then goes to the square root extractor. Note that the pressure correction computer then goes to the square root extractor and that the pressure correction calculation must be done before the square root extraction. this is done to preserve the orifice calculation data, and the same holds true for temperature correction of a flow signal. From the square root extractor, the signal goes to a summer (FY3) which adds the corrected fuel gas flow and the oil flow signals to provide a total fuel flow process variable signal to the total fuel controller.

The total fuel controller receives its remote setpoint from the low level air cross link relay. The inputs to this relay come from the boiler master and the air flow measurement. The relay will select the lowest of these two signals. The purpose of this selection is to prevent a condition where the boiler master calls for more fuel than there is enough air for safe combustion in the boiler. When the system is placed in local automatic or manual mode the controller will not respond to either the boiler master signal or a lower air flow than fuel flow condition.

The output from the total fuel controller (FIC) is then fed to a low level select relay (FY6) and a summer (FY7). The other input to the low level select relay is the output from the fuel gas master pressure controller. If the output from the fuel gas master pressure controller is less than 100%, the low level select relay will limit its output to the oil valve via FIK. If the output from the total fuel controller and the low level select relay are different, the summer will have an output larger than 3 psi and the gas valve will open.

The FIK for the oil valve is the AUTO-MANUAL station whose output is equal to the input when it is in AUTOMATIC. In MANUAL, this FIK control requires a technician to manually control the oil valve.

HANDOUT #1

The FIK for the gas valve is a bias station like the FIK for the oil valve. In AUTOMATIC, the FIK takes the output from the summer, biases it either up ro down, and sends the output to the gas valve. In MANUAL, the technician controls the gas valve manually.

Fuel gas header pressure

Refer to the Master P&ID that accompanies this handout.

Fuel gas header pressure is maintained by three separate controllers. The primary control for fuel gas pressure is done by PIC-614 (refer to the upper left area of the Master P&ID). PIC-614 receives a signal from PT-614 for a process variable, and sends an output to all three boilers. This output is one of the inputs for the Reset Windup Protection Relay described earlier (Diagram 2). This relay sets the ratio of fuel gas to fuel oil in the boilers and allows the boilers to burn as much fuel gas as possible and still control fuel gas header pressure.

There are two other controllers that receive an input from PT-614. They are the natural gas to fuel gas pressure controller (PIC-725) and the propane to fuel gas pressure controller (PIC-726). The PIC-726 is an "emergency only" controller that has only enough capacity for approximately 20 minutes because of tankage. This controller is generally set in MANUAL; however, it could be run on AUTO at a setpoint of less than 25 psig.

Induced draft system

Refer to Diagram 3 that accompanies this handout.

The furnace pressure transmitter (PT) senses the pressure in the boiler and sends a signal to an inverse derivative relay (PY2). The inverse derivative relay dampens out oscillations from the transmitter and sends a signal to the ID (induced draft) pressure controller (PIC) that represents average furnace pressure. The output from the ID pressure controller goes to the damper and also to the overfiring protection controller (PC). The purpose of the protection controller is to prevent the boiler master from firing the boiler harder than the ID fan can keep up with. The protection controller does this by sensing the output of the ID pressure controller and comparing it to a setpoint from a regulator behind the control board. When the ID controller output gets up to 90%, the overfiring protection controller output starts dropping down and limits the boiler master signal through a low-level select relay (PY3).

The low signal select is on the output of each boiler master FIK. The overfiring protection controller is in AUTO all the time and cannot be put in MANUAL by a technician to avoid the possibility of the overfiring control being removed. On supply air failure, a braking device in the ID damper locks the damper in position. There is a hand switch (HS) in the control room that supplies 40 psi to the locking device to reset the damper on return of supply air. The damper can also be reset manually at the damper.

HANDOUT # 1

Forced draft system

Refer to Diagram 4 that accompanies this handout.

To insure that a boiler has enough air to maintain proper combustion for the amount of fuel in the boiler, a control system that compares air flow, flue gas oxygen, total fuel flow, and boiler demand is used. The combustion air flow transmitter (DPT) has two taps on the boiler, one on the south end and one on the north end. As air flow through the boiler increases or decreases, the differential pressure across the boiler goes up or down, and the differential pressure transmitter output goes up or down. This signal is applied to a Baily signal characterizer that examines any given percentage of steam flow and produces an output pressure signal with characteristics that will be the same as if the percentage were at 3% flue gas oxygen. For example, if steam flow is 87 Mlbs/hr (which is 50% of the boiler load on a 0-175 Mlbs/hr boiler) the output of the signal characterizer should be 1 psig out of 2 psig maximum, or 50% on the chart. This system controller produces a linear response in air flow at all boiler loads.

The oxygen content of the flue gas is sensed by a probe installed in the ductwork leaving the boiler. This probe sends a 4-20 mA signal to a current to pressure transducer, and from there, to the input of the oxygen controller. Introducing oxygen into the flue gas (stack gas) can cause problems because if the boiler is not tight due to leaks in the ductwork, air (which is 21% oxygen) will enter and cause the oxygen output to read artificially high. For this reason, a stack gas analyzer is used to examine carbon monoxide (CO), unburned hydrocarbon, and opacity. This system is used instead of an oxygen analyzer. The output from this analyzer is then used to set the remote setpoint for the oxygen controller to optimize boiler efficiency.

The output from the signal characterizer and the output from the oxygen controller are both tied into a Foxboro pneumatic controller (FY1). The output of the oxygen controller will bias the signal from the signal characterizer up and down to control the flue gas oxygen content at a given setpoint. This signal is the process variable for the air flow controller and will cause the forced draft damper on the furnace to open and close. If the flue gas oxygen went up, the signal out of the computer would also go up and the air flow controller would close down the forced draft damper to bring the air flow down and lower the flue gas oxygen content.

The output from the computer goes two directions. One output goes to the air flow controller (FIC) and is used as the measurement, and the other computer output goes to the low level select cross link relay for the total fuel controller system discussed earlier.

The setpoint for the air flow controller in remote comes from the high level select cross link relay (FY2). The inputs to FY2 are boiler demand and total fuel control. If the total fuel flow signal is higher than the boiler demand signal, the fuel flow signal will become the setpoint for the air flow controller.

The air-fail locking device on the FD damper is the same as the one on the ID damper discussed earlier.

HANDOUT #1

Instrument maintenance

When certain instruments and impulse lines require maintenance, certain controllers have to be placed in MANUAL mode to safely complete maintenance.

When an instrument air failure occurs, all fan damper control devices must be reset from their respective boiler control boards. If time permits, the actual damper openings should be compared with their respective boiler board controller output to prevent changing damper position during resetting of the air failure brake. Remember that the instrument air loss results in a mechanical braking of the damper at its current position. The fuel oil control valve, fuel gas control valve, and feedwater control valve on all three boilers reset automatically to current conditions when instrument air pressure is restored.

Steam Header Pressure Controller

Output from the Steam Header Pressure Controller provides the control impulses for the three boiler masters. Here, maintenance procedures are relatively simple. First, the Steam Pressure Recorder: this Moore control system has two separate pressure transmitters for measuring steam header pressure. The transmitter outputs go through a hand switch located on a boiler control board near the bottom. When the switch handle is in the vertical position, one of the transmitters is going on to the recorder. When the switch handle is in the horizontal position, the other transmitter is going to the recorder. This hand switch should be operated periodically to insure that both transmitters are properly working (check upper left loop in Master P&ID). Second, a High Signal Selector Relay (HSSR) has been installed in the mainstream header system. The inputs to the HSSR are the two high pressure steam pressure header transmitters (PT-693 and PT-603A). Should either one of these transmitters fail, the other one will automatically sustain signal input to the Plant Master (PIC-603). In order to check for proper operation of the two transmitters, the hand switch (HS-603) can be used to switch the signal to the recorder (PR-603) from one transmitter to the other. When this relay requires maintenance, the pressure controller (PIC-603) must be in MANUAL.

When one of the pressure transmitters has to be maintained, the HSSR relay will place the other transmitter in control. However, if the impulse line is going to be blown down, place the Plant Master in MANUAL because blowing down one transmitter will cause the other transmitter to bounce.

Fuel Gas Header Pressure

The fuel gas header pressure transmitter (PT-614) sends its signal to three separate controllers (see upper next to left loop in Master P&ID): the PIC-614 which changes the gas firing rate in all three boilers to control the fuel gas header pressure at 34 psig, PIC-725 which changes the setpoint to the natural gas valve local controller to add natural gas in a low fuel gas pressure condition, and PIC-726 which has a local setpoint to add propane in a low fuel gas pressure condition. When maintenance has to be performed on the fuel gas header pressure transmitter, care should be taken that all three controllers are in MANUAL mode. Also, when the impulse lines for FR-612, fuel gas flow into the power station, are to be blown down or the transmitter is to be removed for maintenance, all three of these controllers must be in MANUAL because the fuel gas header pressure transmitter (PT-614), and the fuel gas flow into the Power Station (FR-612) have one common impulse line.

HANDOUT # 1

PC-725 (lower left in Master P&ID) is a local pressure controller whose setpoint can be biased up or down from a board mounted controller PIC-725 (upper left in Master P&ID). The local pressure controller (PC-725) is usually set at 25 psig, and in the event that fuel gas pressure drops to this value, the controller will open the valve and supply natural gas to the fuel gas system. The purpose of the board mounted controller (PIC-725) is to allow the operator to burn a controlled amount of natural gas by placing the PIC-725 controller in MANUAL and opening the valve. An option is for the operator to set the "emergency set pressure" to a value higher than 25 psig by placing the PIC-725 controller in AUTO and adjusting the setpoint to some value above 25 psig (perhaps 30 psig). This is the normal mode of operation for true control as well as true setpoint.

Fuel Gas Flow and Fuel Oil Flow for individual boilers

Refer to Diagram 2 that accompanies this handout.

The fuel gas flow to each individual boiler is measured and sent to a controller which also takes an input from the fuel gas burner pressure transmitter. This controller (FY2) corrects the fuel gas flow signal for changes in fuel gas pressure to give the control scheme a true reading of fuel gas flow. This signal is then passed through a computer which changes the signal to allow for BTU correction. Then, the fuel gas flow signal is applied to a summing relay (FY3) and added with fuel oil flow for a total fuel flow measurement.

When maintenance is performed on the fuel gas flow transmitter, the fuel gas pressure transmitter, or the fuel oil flow transmitter, the total fuel flow controller must be placed in MANUAL and the air flow controller should be put in local AUTOMATIC. This prevents fluctuation in total fuel flow measurement from affecting combustion air while maintenance is performed on any one of the transmitters. The reason for placing the air flow controller in local AUTOMATIC is to allow the oxygen controller to still correct for excess oxygen in the flue gas.

If the oil flow transmitter is to be out of service for an extended period of time, there is a switch behind the board which can be set to allow for the use of the oil pressure signal instead of the oil flow signal for control. However, this is not a good way to run because during an extended period of time a bad oil burner can cause the pressure to fluctuate and bounce the total fuel flow measurement.

Combustion air flow

Refer to Diagram 4 that accompanies this handout.

The combustion air flow transmitter is calibrated to read out in percentage of boiler load. This is to say, at 87 Mlbs/hr the air flow recorder should read 50% because full scale boiler load is 175 M/lbs/hr. The air flow transmitter signal is biased up or down by the flue gas oxygen controller (FY1) and sent to the air flow controller as the measurement signal. In remote mode, the air flow controller receives its setpoint from the boiler master or the measured total fuel flow, whichever is greater. In local AUTO, the setpoint is manually set.

HANDOUT #1

When maintenance is performed on the combustion air flow transmitter, the air flow controller and the total fuel controller should be placed in MANUAL mode, and then both the oil FIK and the gas FIK should be switched to MANUAL.

If maintenance is required on the oxygen system, the oxygen (O_2) controller should be placed in MANUAL. The oxygen (O_2) controller should be placed in MANUAL any time the air flow controller is in MANUAL.

Steam flow, water flow, and level

Refer to Diagram 1 that accompanies this handout.

The steam flow transmitter, the water flow transmitter, and the level transmitter are the three transmitters used to control water flow to the boiler. For a given change in steam flow, the water flow should make a relative equal change in the same direction, and then the level controller adjusts the water flow to keep the level at setpoint. When maintenance is performed on any of the three transmitters (steam flow, water flow, and level), the LIK for the level should be put in MANUAL mode. If maintenance is performed on the steam flow transmitter, the BTU correction controller must also be placed in MANUAL.

Induced draft

Refer to Diagram 3 that accompanies this handout.

The induced draft system operates a straight forward control of the draft pressure in the boiler. The transmitter senses the pressure in the boiler, then sends a signal to the controller, and the controller moves the damper to keep the boiler pressure at setpoint. One special precaution should be taken when maintenance is performed on the induced draft system—make sure the output from the ID controller is not moved above 90%. There is an overfiring protection controller that biases the boiler master signal down when the ID damper is 90% open. This overfiring protection cannot be put in MANUAL from the front of the control board; therefore, it is the maintenance technician's responsibility to insure it never exceeds the 90% setting.

HANDOUT #1

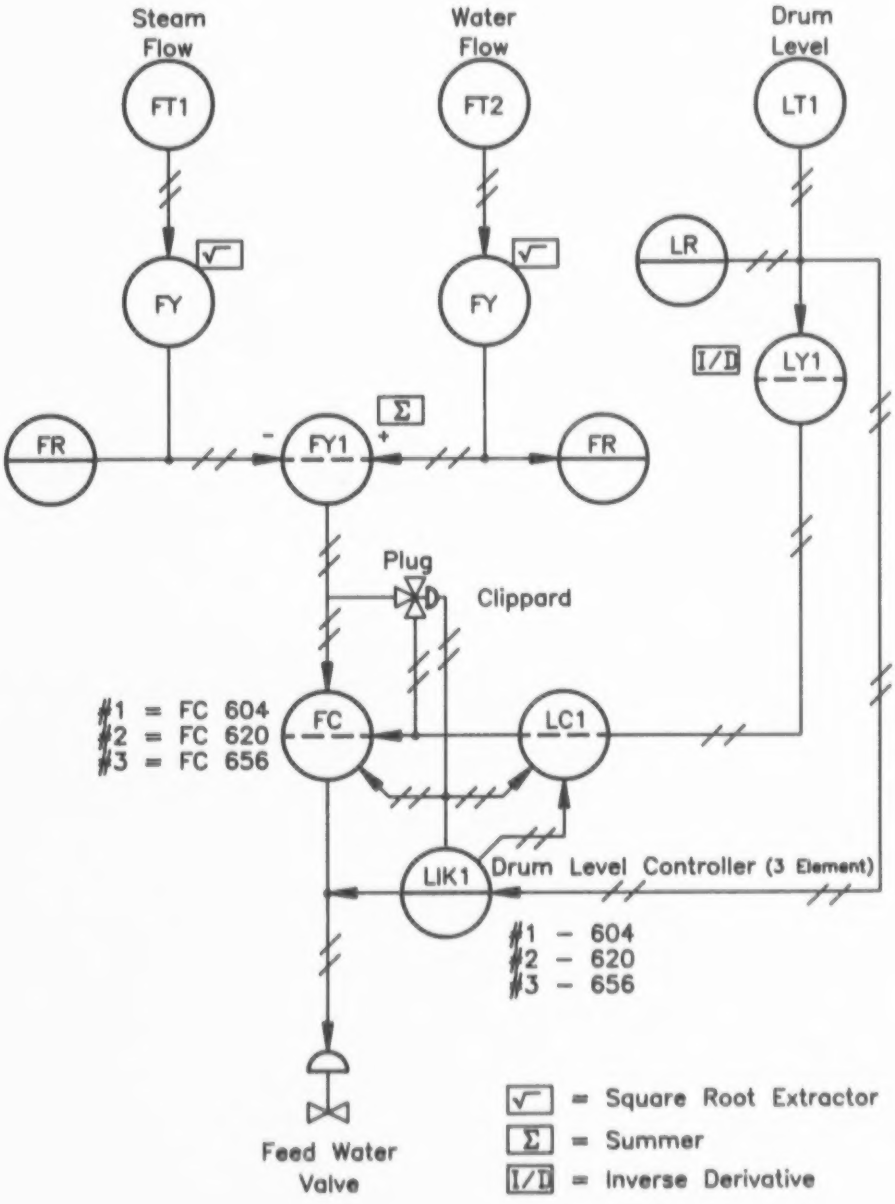
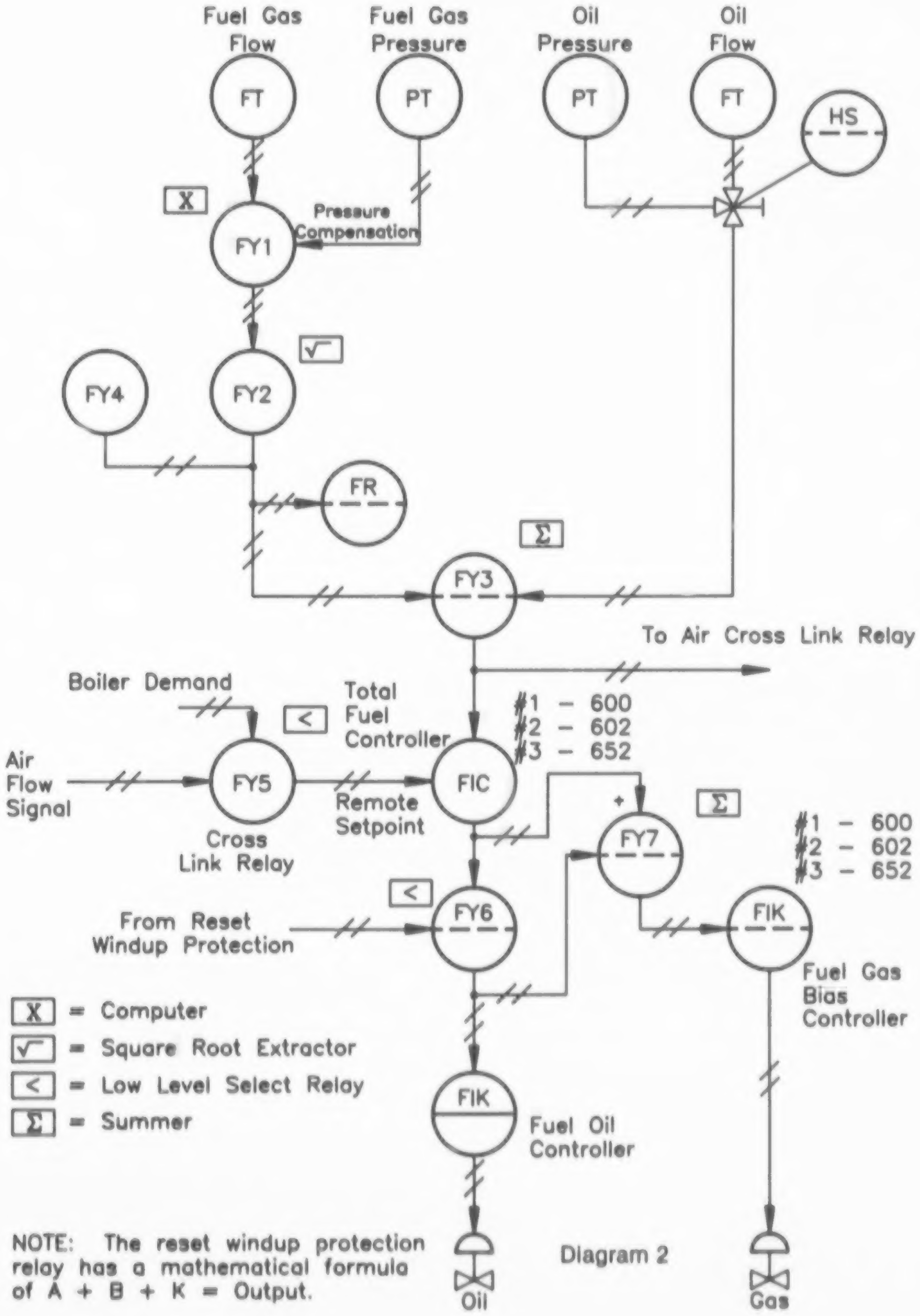

Steam Flow
Water Flow
Drum Level
FT1
FT2
LT1
√‾
FY
√‾
FY
LR
I/D
LY1
FR
Σ
−
FY1
+
FR
Plug
Clippard
#1 = FC 604
#2 = FC 620
#3 = FC 656
FC
LC1
LIK1
Drum Level Controller (3 Element)
#1 − 604
#2 − 620
#3 − 656
Feed Water Valve
√‾ = Square Root Extractor
Σ = Summer
I/D = Inverse Derivative

Diagram 1

HANDOUT #1


Fuel Gas Flow
Fuel Gas Pressure
Oil Pressure
Oil Flow
FT
PT
PT
FT
HS
X
Pressure Compensation
FY1
√‾
FY4
FY2
FR
Σ
FY3
To Air Cross Link Relay
Boiler Demand
<
Total Fuel Controller
#1 – 600
#2 – 602
#3 – 652
Air Flow Signal
FY5
FIC
Remote Setpoint
Cross Link Relay
+
Σ
FY7
#1 – 600
#2 – 602
#3 – 652
<
FY6
From Reset Windup Protection
FIK
Fuel Gas Bias Controller
X = Computer
√‾ = Square Root Extractor
< = Low Level Select Relay
Σ = Summer
FIK
Fuel Oil Controller
Oil
Gas

NOTE: The reset windup protection relay has a mathematical formula of A + B + K = Output.

Diagram 2

HANDOUT #1

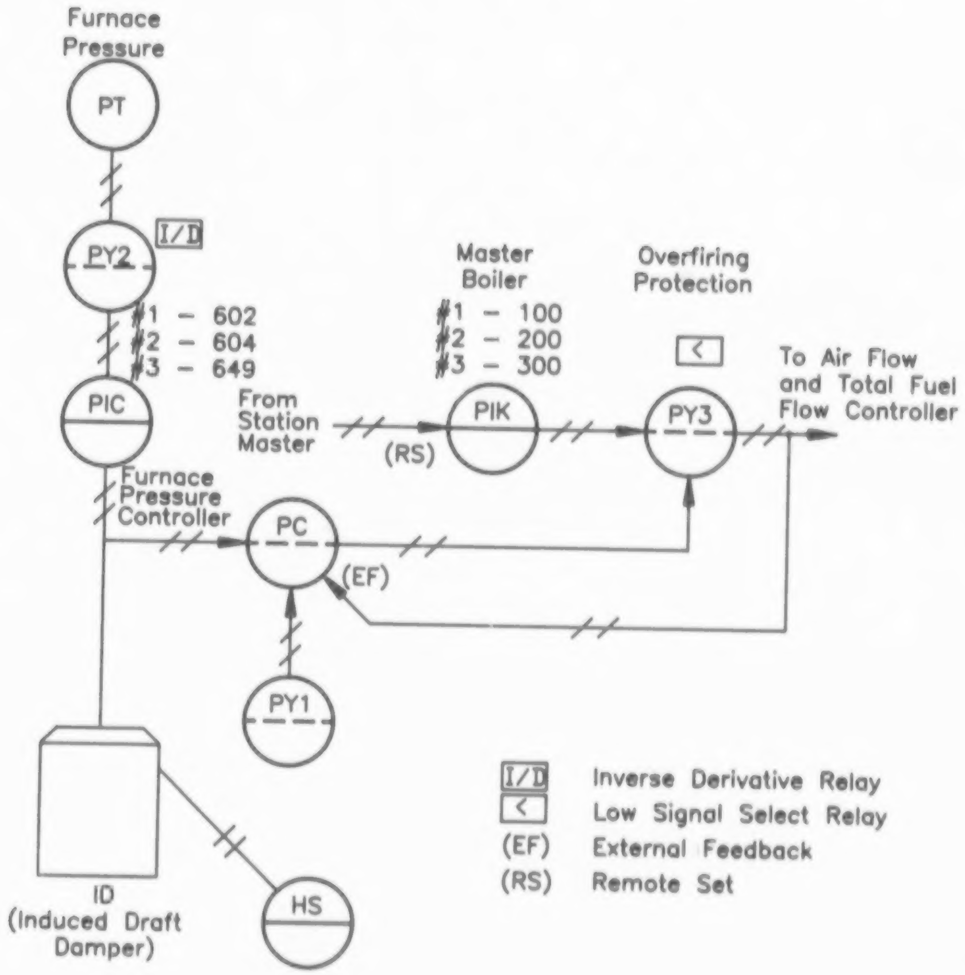

Furnace Pressure
PT
PY2
I/D
#1 – 602
#2 – 604
#3 – 649
PIC
Furnace Pressure Controller
Master Boiler
#1 – 100
#2 – 200
#3 – 300
From Station Master
(RS)
PIK
Overfiring Protection
<
PY3
To Air Flow and Total Fuel Flow Controller
PC
(EF)
PY1
ID (Induced Draft Damper)
HS
I/D Inverse Derivative Relay
< Low Signal Select Relay
(EF) External Feedback
(RS) Remote Set

Diagram 3
(Diagram is typical for boilers #1, #2, and #3)

HANDOUT #1

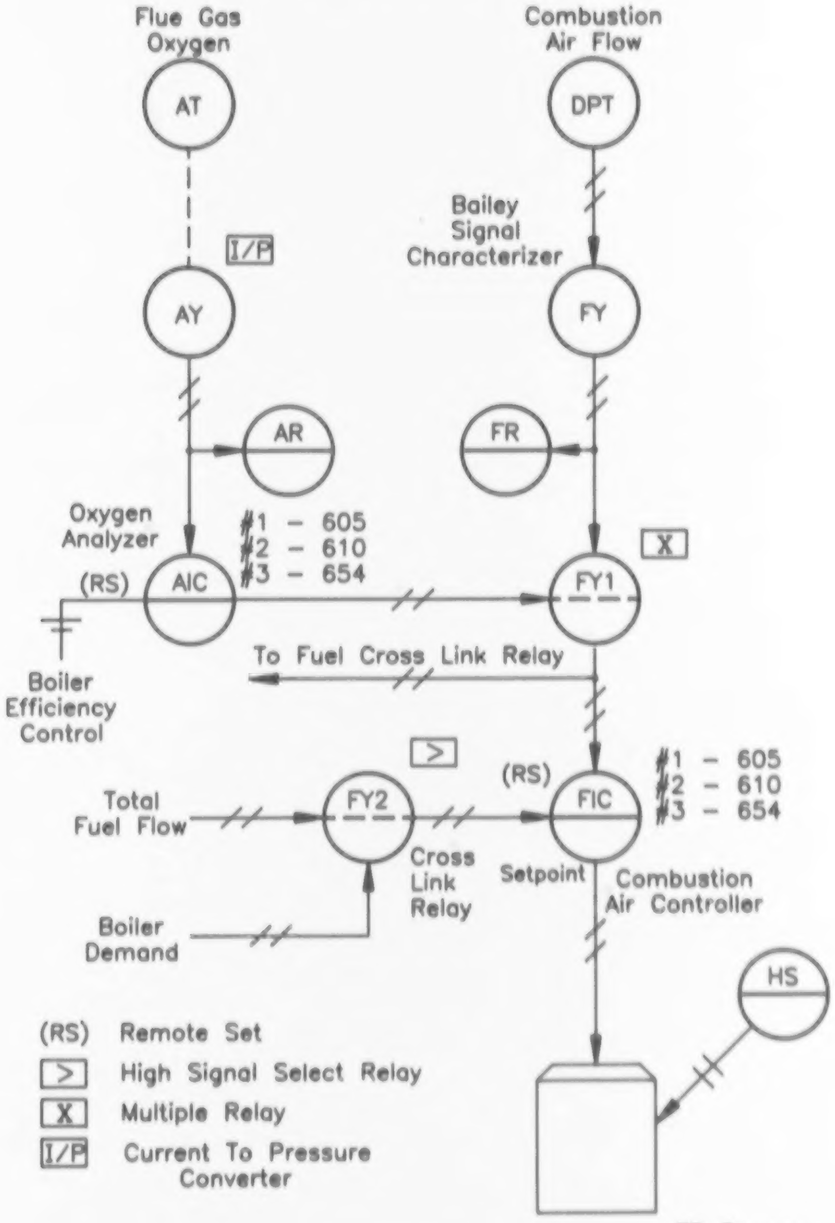
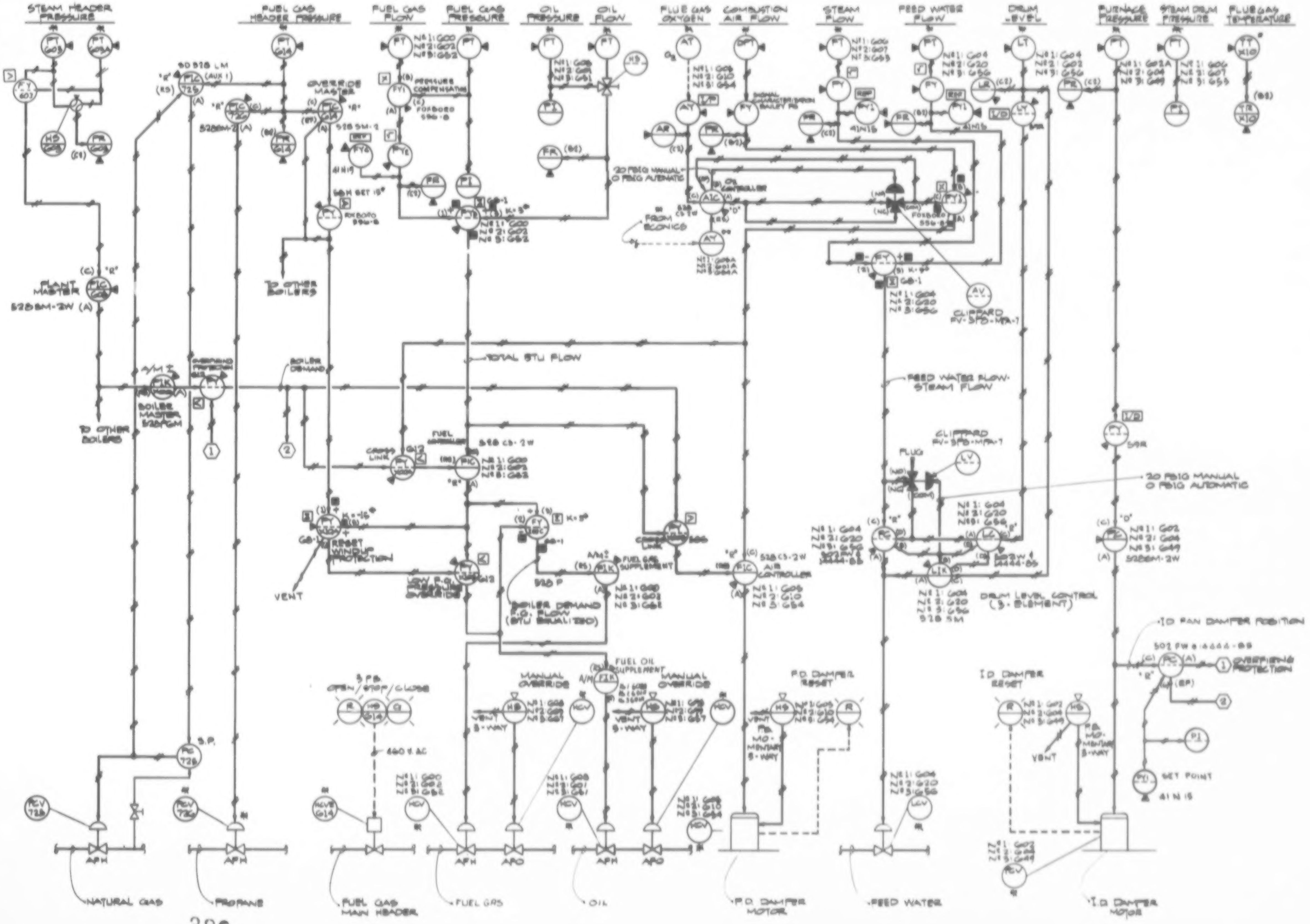

Flue Gas Oxygen
Combustion Air Flow
AT
DPT
Bailey Signal Characterizer
I/P
AY
FY
AR
FR
Oxygen Analyzer
#1 - 605
#2 - 610
#3 - 654
X
(RS)
AIC
FY1
Boiler Efficiency Control
To Fuel Cross Link Relay
>
(RS)
Total Fuel Flow
FY2
FIC
#1 - 605
#2 - 610
#3 - 654
Cross Link Relay
Setpoint
Combustion Air Controller
Boiler Demand
HS
(RS) Remote Set
> High Signal Select Relay
X Multiple Relay
I/P Current To Pressure Converter
FD Damper

Diagram 4
Forced Draft System for Furnace Systems #1, #2, and #3

PI-429


STEAM HEADER PRESSURE
FUEL GAS HEADER PRESSURE
FUEL GAS FLOW
FUEL GAS PRESSURE
OIL PRESSURE
OIL FLOW
FLUE GAS OXYGEN
COMBUSTION AIR FLOW
STEAM FLOW
FEED WATER FLOW
DRUM LEVEL
FURNACE PRESSURE
STEAM DRUM PRESSURE
FLUE GAS TEMPERATURE
OVERRIDE MASTER
PRESSURE COMPENSATION
FOXBORO 556-G
TO OTHER BOILERS
PLANT MASTER
528SM-2W (A)
BOILER MASTER
BOILER DEMAND
TOTAL BTU FLOW
20 PSIG MANUAL 0 PSIG AUTOMATIC
FROM ECONICS
CLIPPARD PV-3FD-MPA-1
FEED WATER FLOW-STEAM FLOW
CLIPPARD PV-3FD-MPA-1
PLUG
20 PSIG MANUAL 0 PSIG AUTOMATIC
CROSS LINK
FUEL CONTROLLER
RESET WINDUP PROTECTION
VENT
LOW F.G. OVERRIDE
BOILER DEMAND F.G. FLOW (BTU EQUALIZED)
FUEL GAS SUPPLEMENT
AIR CONTROLLER
DRUM LEVEL CONTROL (3-ELEMENT)
I.D. FAN DAMPER POSITION
OVERFIRING PROTECTION
SET POINT
FUEL OIL SUPPLEMENT
MANUAL OVERRIDE
MANUAL OVERRIDE
3 P.B. OPEN/STOP/CLOSE
460 V AC
VENT 3-WAY
F.D. DAMPER RESET
P.B. MO-MENTARY 3-WAY
I.D. DAMPER RESET
AFH
AFO
NATURAL GAS
PROPANE
FUEL GAS MAIN HEADER
FUEL GAS
OIL
F.D. DAMPER MOTOR
FEED WATER
I.D. DAMPER MOTOR

INTERACTIVE LOOPS: BOILERS
UNIT VII

ASSIGNMENT SHEET #1 — IDENTIFY CONTROL FUNCTIONS IN INTERACTIVE BOILER LOOPS

Directions: Refer to Handout #1 and the diagrams and P&ID that accompany it to answer the following questions.

1. What is the typical two-fold problem that a boiler control scheme is faced with?

   Answer: ______________________________

   ____

2. In three-element drum level control, steam flow and water flow transmitters send output signals through a square root extractor before they go on to a summing relay. Why is the square root extractor required?

   Answer: ______________________________

   ____

3. Steam flow input goes to the negative input of a summer and water flow input goes to the positive summer input. What happens when both inputs are the same?

   Answer: ______________________________

   ____

4. The total fuel controller receives input from both the boiler master and the air flow measurement, and the controller selects the lowest of the two signals. Why?

   Answer: ______________________________

   ____

5. In an induced draft system, what does the overfiring protection controller (PC) accomplish?

   Answer: ______________________________

   ____

ASSIGNMENT SHEET #1

6. What is used to assure that a boiler has enough air to maintain proper combustion for the amount of fuel in the boiler?

   Answer: ________________________________

   ____

7. Infiltration of air into ductwork can cause oxygen content in a boiler system to read artificially high, and an oxygen analyzer would not work well. What system does work?

   Answer: ________________________________

   ____

INTERACTIVE LOOPS: BOILERS
UNIT VII

ANSWERS TO ASSIGNMENT SHEET

1. To produce high pressure steam for use in power generation, and to control plant fuel gas pressure.
2. To linearize the flow signals.
3. The summer output will remain at 50%.
4. This is to prevent a condition where the boiler master calls for more fuel than there is enough air for safe combustion in the boiler.
5. It prevents the boiler master from firing the boiler harder than the induced draft fan can keep up with.
6. A control system that compares air flow, flue gas oxygen, total fuel flow, and boiler demand.
7. A stack gas analyzer which examines carbon monoxide, unburned hydrocarbon, and opacity.

INTERACTIVE LOOPS: BOILERS
UNIT VII

TEST

NAME ________________________________ SCORE ______________

1. Match the terms on the right with their correct definitions.

______a. The addition or subtraction of a percentage of a signal into or out of a controller

______b. A maintenance procedure that clears the impulse lines that run from an orifice plate to a transmitter

______c. A tank-like device that uses a furnace, heat exchanger, and steam drum to turn water into steam for use in industrial plant operations

______d. Any sudden upset in a process

______e. A smooth transition from automatic to manual or manual to automatic operation

______f. A control strategy that uses controllers in series, one after the other, to improve control output

______g. The rapid burning of oxygen and fuel to produce heat

______h. The restriction of an oscillating signal so that it increases or decreases more slowly

______i. The gas flow through a furnace created by the expansion of gases, and the action of lighter gas going up a furnace stack

______j. A form of control necessary in complex plan operations where the controller action in one loop produces an outcome that influences another loop

______k. The measurement of reflected light used to determine the percentage of particulate matter such as smoke and soot in exhausted flue gases

1. Cascade
2. Ramping
3. Draft
4. Bias
5. Solid fuels
6. Boiler
7. Opacity
8. Bounce
9. Blow down
10. Interactive control
11. Combustion
12. Superheated steam
13. Damping
14. Bumpless

TEST

_____l. A condition where a controller will exceed the 100% signal above the 15 psi standard or below the 3 psi standard

_____m. Materials such as coal and wood that are burned in a furnace, and must be handled mechanically

_____n. Water that is turned into steam in the steam drum of a furnace, and then reheated to add more heat energy before it goes to run a load

2. Select true statements concerning principles of interaction by placing an "X" beside each statement that is true.

_____a. Industrial process control is seldom accomplished with individual loops that control a single parameter; rather, processes are normally comprised of multiple loops interacting to control a single parameter.

_____b. In many process controls, the interaction of loops is created by using the output from a loop which is measuring one variable to provide the setpoint for another loop that is working on another variable.

_____c. One effective interaction control strategy is derivative control where two levels of control are very common.

_____d. Cascading more than two levels of control can create several problems such as cascading the gains, noise multiplication, and delays in action on some process variable.

_____e. Interaction between loops in a large process is unavoidable, and since the product is normally acted on by all the loops in a control system, interaction is part of system design, and therefore desirable.

_____f. Since the boiler system is one of the most commonly used systems in process industries, boiler sub-systems provide excellent examples of principles of interaction.

3. Complete statements concerning oil combustion control systems by circling the material that best completes each statement.

a. Combustion control systems in boilers control the burning of fuel to produce heat that converts (**water into steam, media into product**).

b. Since oil, gas, and coal are all commonly used boiler fuels, each fuel type requires a (**separate, similar**) type of combustion control.

TEST

c. In oil combustion control, the general requirements are the presence of air and **(some material, pressure)** that can rapidly combine with the oxygen in the air to form heat.

d. In oil, gas, and coal, the materials that combine with oxygen are hydrogen, carbon, and traces of other materials such as **(sulfur, ash)**.

e. To achieve efficient combustion, an oil combustion system must control:

   1) The flow of oil into the **(combustion chamber, charge line)**.

   2 The flow of air into the **(combustion chamber, pressure chamber)**.

   3 Gases from the **(stack, furnace)**.

   4 Pressure inside the **(furnace, stack)**.

f. An oil combustion control system must continuously balance the heat input with the demand for heat to produce steam while using the minimum amount of **(fuel and air, time)**.

g. Another equally important objective of combustion control is to keep the furnace in its **(safe operating zone, highest output mode)**.

4. Complete statements concerning gas and coal combustion systems by circling the material that best completes each statement.

a. Gas combustion systems **(parallel, are unlike)** oil combustion systems for the most part, **(but, and)** there are two major differences.

b. First, gas can be compressed, and **(fuel pressure, compression ratio)** is an important element.

c. Second, the BTU value of gas is **(much higher than, as high as)** oil, and this becomes a control consideration.

d. Coal and oil combustion systems parallel each other for the most part, except that coal is a solid which requires **(mechanical loading, sizing)**.

e. With coal combustion, the size of coal pieces, density, and thickness become important as well as control of the **(velocity, volume)** of air passing over or through the coal to support combustion.

TEST

5. Solve problems concerning EPA guidelines for exhausted flue gases by selecting the correct answer to each of the following questions.

   a. A popular method of monitoring the opacity of exhausted flue gases is what, using a laser device or directing a light across the flue and measuring the amount of light reflected back to the source?

   Answer: ______________________________

   b. If half the light directed from a source is reflected back across the flue, the opacity rating at that moment would be what, 50% or 75%?

   Answer: ______________________________

6. Select true statements concerning furnace pressure control by placing an "X" beside each statement that is true.

   _____a. Pressure inside the furnace of a boiler is important to the production of the heat required to produce pressure.

   _____b. Pressure is controlled by measuring the inputs such as fuel and air, and the outputs such as leakage, flue gas, and entrained solids like ash, reaction gases, and byproducts that leave with the flue gas.

   _____c. Because of thermal expansion and combustion reaction, the volume of gas leaving a furnace is much less than the volume of gas entering, so the real control problem is that of balancing mass in with mass out.

   _____d. The draft that causes the pressure difference may be a natural draft caused by gas moving out of the furnace and up the stack, or it may be induced or forced by fans.

   _____e. Induced draft refers to pulling the gases out of the stack end of the furnace by fan.

   _____f. Forced draft refers to forcing air into the front end of the system by fan.

   _____g. Because the furnace pressure is small, 1 to 3 inches of water, the pressure is measured by a special draft gauge, and transmitted to the controller which in turn controls a final element that is either a fan control for induced or forced draft, or a damper near the stack if it is a natural draft furnace.

7. Solve problems concerning steam drum control by selecting the correct answer to each of the following questions.

   a. The control task of a steam drum is to provide a steam/replacement water balance of what, a pound of input water for each pound of steam output or two pounds of input water for each pound of steam output?

   Answer: ______________________________

TEST

b. If steam drum level gets too high, solids in the water could damage steam-operated equipment, and also cause the boiler tubes to what, block up and operate inefficiently or heat up and warp?

Answer: ______________________________

8. Complete statements concerning steam temperature control by circling the material that best completes each statement.

   a. In systems that require superheated steam, the superheaters are normally (**special alloy, aluminum**) heat exchangers arranged in stages that follow the output from the steam drum.

   b. Temperature of the steam must be controlled in order to produce the proper superheated steam temperature of approximately (**850°F, 212°F**), but not damage the special alloy heat exchangers.

   c. Control is achieved with (**thermocouple, infrared**) measurement at the output of the steam, and this controls a water injection system between the superheaters to give the correct temperature.

9. Solve problems concerning loop isolation for maintenance by selecting the correct answer to each of the following questions.

   a. In order to remove a loop from an interactive process, the entire system must be examined to determine what, what affect removing the loop would have on the system or how much down time will be required?

   Answer: ______________________________

   b. Except for some critical processes, a normal loop during maintenance can continue to what, operate or operate at half production?

   Answer: ______________________________

10. Arrange in order the steps in a blow down procedure by placing the correct sequence number in the appropriate blank.

_____a. Permit the steam to blow momentarily, then shut it off.

_____b. Reconnect the impulse lines.

_____c. Open the impulse lines with appropriate safety precautions.

_____d. Permit water to blow out of the lines until steam appears.

_____e. Turn steam on again and allow enough time for it to condense back to water so the transmitter will give a proper reading.

TEST

11. Solve problems concerning return to normal operations by selecting the correct answer to each of the following questions.

    a. Restoring automatic operations to a loop that has been down for maintenance basically requires what, rechecking the entire system or reversing the procedure for bringing the loop out of service?

       Answer: ____________________

    b. When a loop has been down for service, it should at first be brought back to service in what mode, automatic or manual?

       Answer: ____________________

(NOTE: If the following activity has not been accomplished prior to the test, ask your instructor when it should be completed.)

12. Identify components and their functions in a typical interactive loop. (Assignment Sheet #1)

INTERACTIVE LOOPS: BOILERS
UNIT VII

ANSWERS TO TEST

1.

a.	4	f.	1	k.	7
b.	9	g.	11	l.	2
c.	6	h.	13	m.	5
d.	8	i.	3	n.	12
e.	14	j.	10		

2. b, d, e, f

3. a. Water into steam
   b. Separate
   c. Some material
   d. Sulfur
   e. 1) Combustion chamber
      2) Combustion chamber
      3) Stack
      4) Furnace
   f. Fuel and air
   g. Safe operating zone

4. a. Parallel, but
   b. Fuel pressure
   c. Much higher than
   d. Mechanical loading
   e. Velocity

5. a. Directing light across the flue and measuring the amount of light reflected back to the source
   b. 50%

6. b, d, e, f, g

7. a. A pound of input water for each pound of steam output
   b. Heat up and warp

8. a. Special alloy
   b. 850°F
   c. Thermocouple

ANSWERS TO TEST

9. a. What affect removing the loop would have on the system
   b. Can continue to operate

10. a. 3
    b. 4
    c. 1
    d. 2
    e. 5

11. a. Reversing the procedure for bringing the loop out of service
    b. Manual

12. Evaluated to the satisfaction of the instructor

INTERACTIVE LOOPS: DISTILLATION TOWERS

UNIT VIII

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss the principles of distillation, preprocessing, and system operations in a crude oil distillation tower. The student should also be able to identify control functions in a typical distillation tower interactive control loop. These competencies will be evidenced by correctly completing the procedures outlined in the assignment sheet, and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to interactive loops:distillation towers with their correct definitions.
2. Select true statements concerning principles of distillation.
3. Solve problems concerning preprocessing.
4. Solve problems concerning system overview.
5. Select true statements concerning heat balance in a distillation tower.
6. Solve problems concerning loop isolation for maintenance.
7. Complete statements concerning return to normal operations.
8. Identify control functions in a distillation tower loop. (Assignment Sheet #1)

INTERACTIVE LOOPS: DISTILLATION TOWERS
UNIT VIII

SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information and assignment sheets.

C. Make transparency.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Use Handout #1 to reinforce materials in the information sheet, but have available other P&IDs to show students examples of other types of interactive loops in distillation towers.

G. Arrange for students to visit a local or area oil refinery, and have them report on the control schemes they observe.

H. Invite an engineer or operator from a local or area oil refinery to talk to the class about interactive controls and the variety of control applications required in a refinery.

I. Give test.

REFERENCES USED IN DEVELOPING THIS UNIT

A. Hall, Ronald P. *Automated Process Control Systems (Concepts and Hardware*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1981.

B. Johnson, Curtis D. *Process Control Instrumentation Technology*. New York, NY: John Wiley & Sons, 1982.

C. Liptak, Bela G. *Instrumentation Processing in the Industries*. Philadelphia, PA: Chilton Book Company, 1973.

D. Potvin, John. *Applied Process Control Instrumentation*. Reston, VA: Reston Publishing Co., 198.

E. Tyson, Forrest. *Industrial Instrumentation*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1980.

INTERACTIVE LOOPS: DISTILLATION TOWERS
UNIT VIII

INFORMATION SHEET

I. **Terms and definitions**

A. Bottoms — The heavy byproducts that settle out of crude oil during the distillation process and are later used as materials for waterproofing, roofing, and blacktopping roads

B. Charge rage — The rate at which new product is fed into a distillation tower

C. Crude oil — The raw material from an underground oil supply that is pumped into a petroleum refining process where oil byproducts are separated and refined (also called "crude")

D. Cut-point — The boiling point where crude oil byproducts such as napatha, diesel, and asphalt separate from the raw crude

E. Draw off — The process of removing a product from a tray in a distillation tower

F. End point — The point at which a product sample is terminated and evaluated

G. Flash point (or zone) — That part of a fractionation tower where the different fractions of petroleum vaporize or flash into gas and rise up to a designated tray in a distillation tower

H. Fractionation tower (distillation tower) — A tower where petroleum products are separated by heating until the various fractions reach cut-points where they can be separated, and accumulated in trays at different heights in the tower

I. Pumparound system — A process where liquified fractions of products picked up in a tray are then pumped up to another tray to promote condensation of the fraction, and to remove heat from the tower

J. Viscosity — The internal friction of a fluid which decreases in liquids as temperature rises and increases in gases as temperature rises

K. Volatile — Capable of evaporating or vaporizing rapidly

II. **Principles of distillation**

A. A typical distillation tower is a round steel structure whose height and diameter are dependent on the volume of crude to be processed per hour.

B. To begin the process, crude oil is heated at a point external to the tower, and introduced at a point near the bottom of the tower.

C. Under pressure from the furnace, the heated crude enters the tower, immediately vaporizes, and the products separate as they rise in the tower.

INFORMATION SHEET

D. Vapors rise in the tower according to their weight, with the lightest products going to the top, and other products to lower levels.

E. Trays are placed at the levels where the vapor representing the product fraction condenses, and the various product fractions are trapped at different heights in the tower where they can be drawn off for further processing.

F. Crude distillation towers usually operate at atmospheric pressure, but some towers used for further distillations, such as distillation of the bottoms, run at a vacuum.

III. **Preprocessing**

A. Because salt that is leached out of the surrounding earth mixes with crude oil deposits, the salt has to be removed before the crude can be heated and sent to the distillation tower.

B. Removing salt is accomplished with a desalter, a vessel that mixes water with the crude, and washes the salt out.

C. The mixture of water and crude is allowed to settle, and the natural separation of oil and water removes the salt.

D. Preprocessing is very important because salt is particularly hard on the metal vessels that process the crude at high temperatures.

IV. **System overview** (Transparency 1)

A. After desalting, crude is preheated by steam in two or more stages before entering a multi-pass furnace.

B. From the furnace, the crude is pumped into an atmospheric pressure tower near the bottom of the distillation tower.

C. Crude enters the tower at about 700°F at a point where it is about half vaporized so the various products will flash into their fractions.

D. The lightest product flashes first, the next lightest flashes second, and so on in order of product weight.

E. After lighter products vaporize, the tar products are left in the bottom of the vessel.

F. Normal output from an atmospheric crude tower produces seven products in order of their weight:

1. Light naptha goes to the seventh or highest trays
2. Heavy naptha goes to the sixth trays

INFORMATION SHEET

3. Kerosene goes to the fifth trays
4. Diesel goes to the fourth trays
5. Gasoline goes to the third trays
6. Oil goes to the second trays
7. Tar bottoms go to the first or lowest trays

G. Lighter products are removed from the top of the tower, and sent on for further processing, and the asphalt type products at the bottom are heated with steam and drawn off for use as road oil and other heavier applications.

V. **Heat balance in a distillation tower**

A. The trays that catch the various fractions of the distilled liquid inside the tower are perforated to allow vapors to rise through the trays until they find the appropriate height according to density.

B. Most of the trays have a pumparound feature that pumps product from one tray to a higher tray, after cooling it, to cause further vaporization and refinement, and remove heat from the tower for control purposes.

C. When the product fraction is drawn from the tower, it is normally drawn through a decoupling system that will draw part of the tray output into a steam stripper where some of the product is returned due to vaporization in the stripper.

(NOTE: This device is another very simple distillation tower designed to strip some of the product away, and return part of it to the tower above the tray that it came from.)

D. To control balance in the tower, the amount of product leaving the tower is compared to the total product flow in the original tower.

E. If an upset occurs in the tower because of excessive loss of heat due to product leaving the tower, the entire process goes out of control.

F. The control of heat balance in a distillation tower is critical to proper operation, and the product taken from the tower is decoupled from the system specifically to help minimize upset of the heat balance.

G. The entire distillation process is controlled by heat, and the production of crude oil fractions requires a delicate balance.

INFORMATION SHEET

VI. Loop isolation for maintenance

A. Any loop that is interactive cannot be shut down for maintenance or repair without causing a problem with the loops around it.

B. In order to remove a loop from an interactive process, the entire process must be examined, and the extent and affect of removing the loop determined.

C. Once the extent of interaction is evaluated, a plan must be formulated to remove the loop without shutting down the entire process, if possible.

D. Some loops are critical enough that the entire process must be shut down to service them.

E. Normally, the process can be run in some emergency mode during maintenance while the questionable loop is removed by placing it into a manual control mode along with interactive loops.

F. The operator can manually control the process to compensate for the lack of that part of the system receiving service.

G. Many distillation towers have a process operations group that normally take charge of plans for removing and restoring troublesome loops from an operating system.

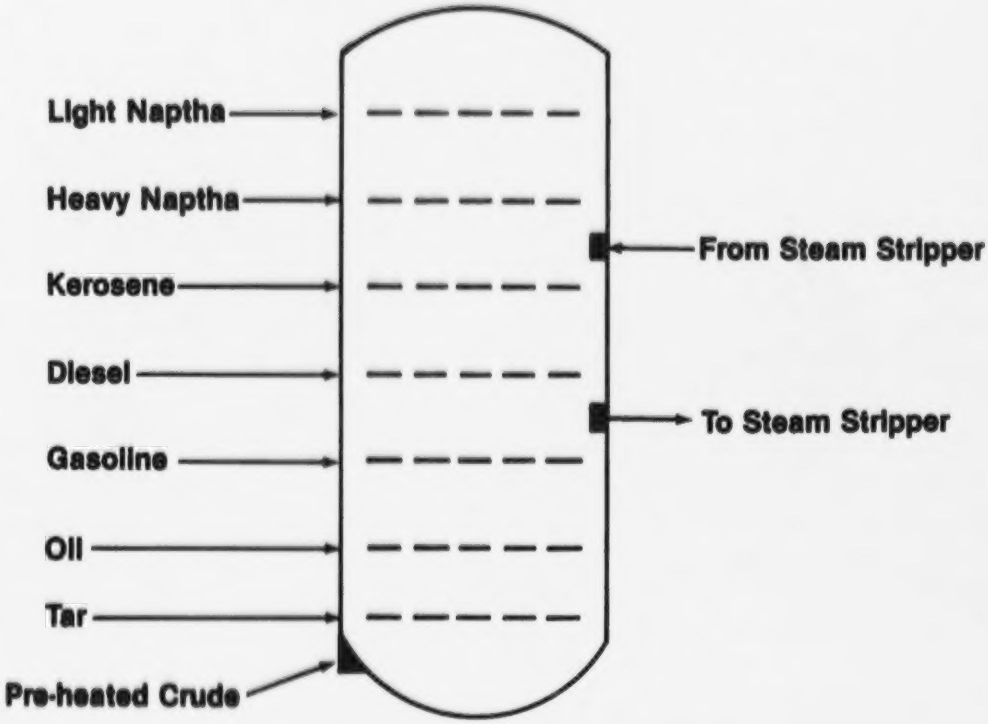
VII. Return to normal operations

A. Restoring automatic operations to a process that has been down for maintenance requires reversing the procedure for bringing the loop out of service.

B. First, the loop is brought on line manually, and the interactive loops operating around it are switched to automatic in some critical order.

C. Next, the newly serviced loop is placed on line in the proper order, and switched to automatic mode.

Products Formed in Distillation


Light Naptha
Heavy Naptha
From Steam Stripper
Kerosene
Diesel
To Steam Stripper
Gasoline
Oil
Tar
Pre-heated Crude

INTERACTIVE LOOPS: DISTILLATION TOWERS
UNIT VIII

HANDOUT #1 — DRAWING/DECOUPLING CONTROLS

Background

In a crude distillation process, the procedure for drawing the fraction of product from the tower is critical. That is why the output from specific trays is decoupled with a stripper that isolates the output from on-going distillation in the tower, as well as recovering more of the volatile product. The interaction of level, temperature, and flow loops are necessary to control the product drawing/decoupling system, and Figure 1 shows how the loops interact.

Drawing and decoupling

The product is drawn from the crude tower trays into the steam stripper at a rate controlled by the level of liquid in the stripper, and a calculated mix of approximately ½ pound of steam per gallon of product. The volatile part of the product is stripped by the steam, and returned to the tower with the steam while the product is drawn from the process at a rate determined by calculations of a computer controller which sends information to a flow control valve. Excess heat is removed by a heat exchanger before the product enters the control cluster.

Flow control

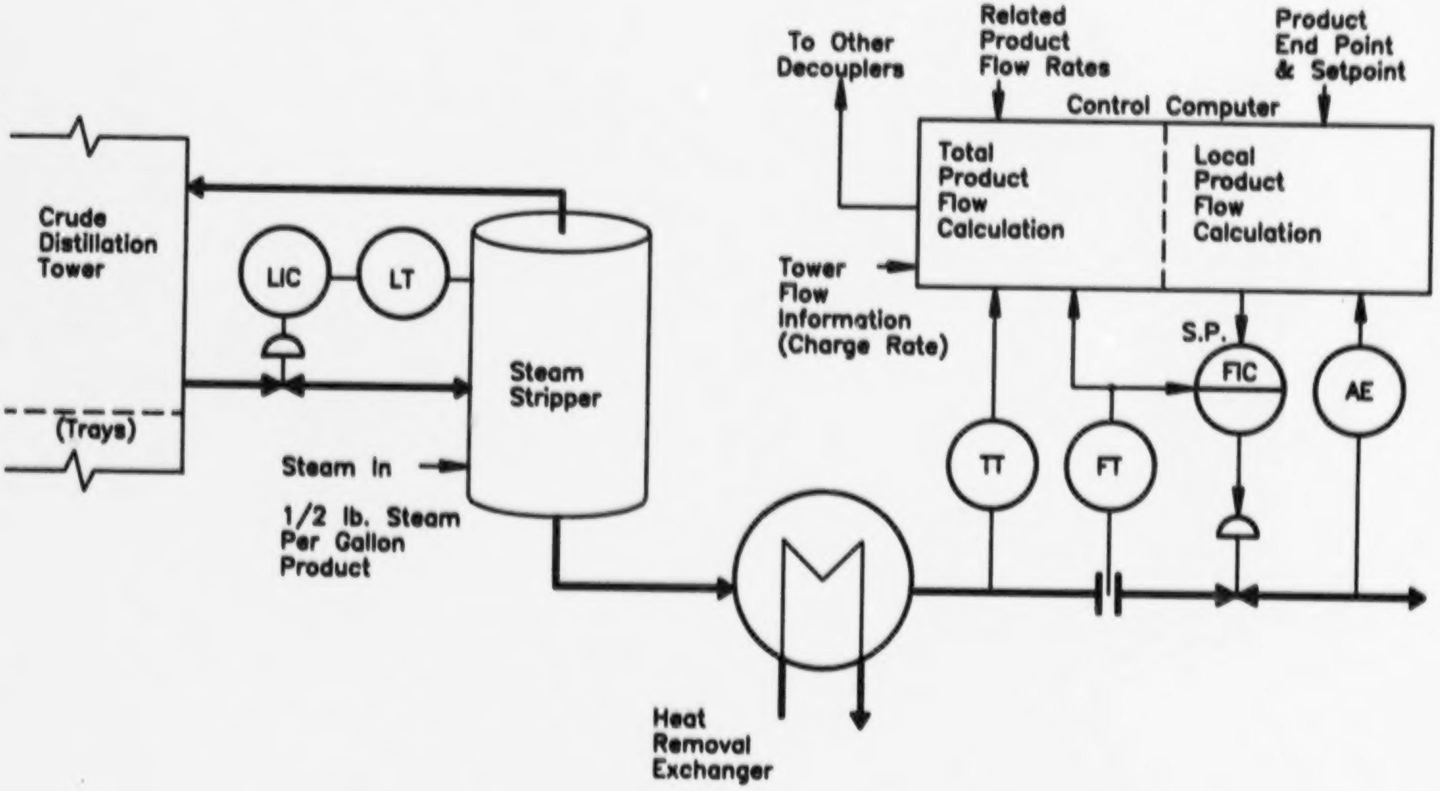
The flow control calculations are the interaction of the product after the heat exchange, the end point and setpoint information from the central process control console, the flow or related products from other trays, the tower charge rate, and product analysis such as viscosity.

Conclusions

Since a distillation process is controlled by heat, and the production of crude oil fractions requires a delicate balance, only an interactive system can accomplish the required control. All of the information from level, temperature, flow, analysis, and input from other locations form the interactive system that controls a complex process. The interactive system controls product output from the tower, along with heat removal, and stripping of volatile materials form the product as associated control outputs.

HANDOUT # 1

FIGURE 1


To Other Decouplers
Related Product Flow Rates
Product End Point & Setpoint
Control Computer
Total Product Flow Calculation
Local Product Flow Calculation
Tower Flow Information (Charge Rate)
Crude Distillation Tower
(Trays)
LIC
LT
Steam Stripper
Steam In
1/2 lb. Steam Per Gallon Product
Heat Removal Exchanger
S.P.
FIC
AE
TT
FT

INTERACTIVE LOOPS: DISTILLATION TOWERS
UNIT VIII

ASSIGNMENT SHEET #1 — IDENTIFY CONTROL FUNCTIONS IN A DISTILLATION TOWER LOOP

Directions: Refer to Handout #1 and Figure 1 of Handout #1 to answer the following questions.

1. What kinds of information are required to control a distillation tower?

   Answer: ______________________________

   ____

   ____

2. What is the name of the device used in the drawing/decoupling of product taken from the distillation tower trays?

   Answer: ______________________________

3. Product is drawn and decoupled according to what approximate steam to product ratio?

   Answer: ______________________________

4. The exchange of product from drawing/decoupling back to the distillation trays is based on what sort of information?

   Answer: ______________________________

   ____

5. Name the interactive loops required to control the product drawing/decoupling system?

   Answer: ______________________________

   ____

INTERACTIVE LOOPS: DISTILLATION TOWERS
UNIT VIII

ANSWERS TO ASSIGNMENT SHEET

1. Level, temperature, flow, analysis, and input from other locations
2. A stripper
3. Approximately ½ pound of steam to a gallon of product
4. Calculations made by a computer controller
5. Level, temperature, and flow

INTERACTIVE LOOPS: DISTILLATION TOWERS
UNIT VIII

TEST

NAME ______________________________ SCORE ______________

1. Match the terms on the right with their correct definitions.

______a. The rate at which new product is fed into a distillation tower

______b. The raw material from an underground oil supply that is pumped into a petroleum refining process where oil byproducts are separated and refined

______c. The boiling point where crude oil byproducts such as napatha, diesel, and asphalt separate from the raw crude

______d. The process of removing a product from a tray in a distillation tower

______e. The point at which a product sample is terminated and evaluated

______f. That part of a fractionation tower where the different fractions of petroleum vaporize or flash into gas and rise up to a designated tray in a distillation tower

______g. A tower where petroleum products are separated by heating until the various fractions reach cut-points where they can be separated, and accumulated in trays at different heights in the tower

______h. A process where liquified fractions of products picked up in a tray are then pumped up to another tray to promote condensation of the fraction, and to remove heat from the tower

______i. The internal friction of a fluid which decreases in liquids as temperature rises and increases in gases as temperature rises

______j. Capable of evaporating or vaporizing rapidly

______k. The heavy byproducts that settle out of crude oil during the distillation process and are later used as materials for waterproofing, roofing, and blacktopping roads

1. Fractionation tower
2. Draw off
3. Viscosity
4. Charge rate
5. Pumparound system
6. Crude oil
7. Volatile
8. Cut-point
9. End point
10. Flash point
11. Bottoms

TEST

2. Select true statements concerning principles of distillation by placing an "X" beside each statement that is true.

_____a. A typical distillation tower is a round steel structure whose height and diameter are dependent on the type of crude to be processed.

_____b. To begin the process, crude oil is heated at a point external to the tower, and introduced at a point near the bottom of the tower.

_____c. Under pressure from the furnace, the heated crude enters the tower, immediately vaporizes, and the products separate as they rise in the tower.

_____d. Vapors rise in the tower according to their temperature, with the hottest products going to the top, and other products to lower levels.

_____e. Trays are placed at the levels where the vapor representing the product fraction condenses, and the various product fractions are trapped at different heights in the tower where they can be drawn off for further processing.

_____f. Crude distillation towers usually operate at atmospheric pressure, but some towers used for further distillations, such as distillation of the bottoms, run at a vacuum.

3. Solve problems concerning preprocessing by selecting the correct answer to each of the following questions.

a. Preprocessing basically concerns itself with what, the removal of sulphur from crude oil or the removal of salt from crude oil?

Answer: ____

b. A desalter is a device that removes salt by what, boiling the salt out or washing the salt out?

Answer: ____

4. Solve problems concerning system overview by selecting the correct answer to each of the following questions.

a. Crude oil is first pumped into a multi-pass furnace and then into what point on a distillation tower, a point near the bottom of the tower or a mid-point on the tower?

Answer: ____

b. What happens to products that enter a distillation tower; do they break down into other products or do they flash into their fractions?

Answer: ____

TEST

c. During processing, which product would go to higher trays in a distillation tower, light naptha or gasoline?

Answer: ______________________________

d. Products are separated in a distillation tower according to what, their charge rate or their weight?

Answer: ______________________________

5. Select true statements concerning heat balance in a distillation tower by placing an "X" beside each statement that is true.

_____a. The trays that catch the various fractions of the distilled liquid inside the tower are perforated to allow vapors to rise through the trays until they find the appropriate height according to density.

_____b. Most of the trays have a pumparound feature that pumps product from one tray to a higher tray, after cooling it, to cause further vaporization and refinement, and remove heat from the tower for control purposes.

_____c. When the product fraction is drawn from the tower, it is normally drawn through a decoupling system that will draw part of the tray output into a steam stripper where some of the product is returned due to vaporization in the stripper.

_____d. To control balance in the tower, the amount of product leaving the tower is immediately weighed.

_____e. If an upset occurs in the tower because of excessive loss of heat due to product leaving the tower, the entire process is shut down.

_____f. The control of heat balance in a distillation tower is critical to proper operation, and the product taken from the tower is decoupled from the system specifically to help minimize upset of the heat balance.

_____g. The entire distillation process is controlled by heat, and the production of crude oil fractions requires a delicate balance.

6. Solve problems concerning loop isolation for maintenance by selecting the correct answer to each of the following problems.

a. Any loop that is interactive cannot be shut down for maintenance without causing what, a need to shut down the entire process or a problem with the loops around it?

Answer: ______________________________

b. For removing and restoring troublesome loops on distillation towers, many companies have what, a general shut-down procedure or a process operations group that takes charge?

Answer: ______________________________

TEST

7. Complete statements concerning return to normal operations by circling the material that best completes each statement.

   a. Restoring **(automatic, manual)** operations to a process that has been down for maintenance requires reversing the procedure for bringing the loop out of service.

   b. First, the loop is brought on line manually, and the interactive loops operating around it are switched to automatic in **(some critical order, reverse order)**.

   c. Next, the newly serviced loop is placed on line in the proper order, and switched to **(automatic, manual)** mode.

(NOTE: If the following activity has not been accomplished prior to the test, ask your instructor when it should be completed.)

8. Identify components and their functions in a typical interactive distillation tower loop. (Assignment Sheet #1)

INTERACTIVE LOOPS: DISTILLATION TOWERS
UNIT VIII

ANSWERS TO TEST

1. a. 4
   b. 6
   c. 8
   d. 2
   e. 9
   f. 10
   g. 1
   h. 5
   i. 3
   j. 7
   k. 11

2. b, c, e, f

3. a. The removal of salt from crude oil
   b. By washing it out

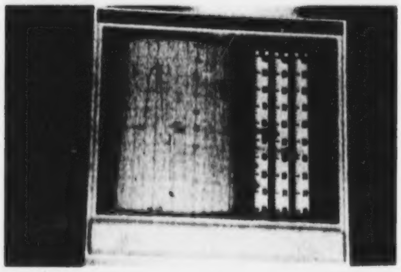
4. a. The bottom of the tower
   b. They flash into their fractions
   c. Light naptha
   d. Their weight

5. a, b, c, f, g

6. a. A problem with the loops around it
   b. A process operations group that takes charge

7. a. Automatic
   b. Some critical order
   c. Automatic

8. Evaluated to the satisfaction of the instructor



INTERACTIVE LOOPS: BATCH PROCESSES

UNIT IX

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss the fundamentals of interactive batch loops, and how they are controlled. The student should also be able to list procedures for servicing a batch loop and returning to normal operations, and be able to identify control functions in a typical batch loop process. These competencies will be evidenced by correctly completing the procedures outlined in the assignment sheet, and by scoring a minimum of 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to interactive loops: batch processes with their correct definitions.
2. Select true statements concerning fundamentals of batch processing.
3. Solve problems concerning controlling batch processes.
4. Select true statements concerning system overview.
5. Solve problems concerning loop isolation for maintenance.
6. Complete statements concerning return to normal operations.
7. Identify control functions in a typical batch loop process. (Assignment Sheet #1)

INTERACTIVE LOOPS: BATCH PROCESSES
UNIT IX

SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information and assignment sheets.

C. Make transparency.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Have available P&IDs other than the one in this unit to demonstrate how batch processes work in various industrial processes.

G. Arrange for students to visit a local or area company that operates a batch process, and have students report on interactive control strategies they observe.

H. Invite the supervisor of a local or area batch processor to talk to the class about managing and maintaining a batch process.

I. Give test.

REFERENCES USED IN DEVELOPING THIS UNIT

A. Hall, Ronald P. *Automated Process Control Systems (Concepts and Hardware*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1981.

B. Johnson, Curtis D. *Process Control Instrumentation Technology*. New York, NY: John Wiley & Sons, 1982.

C. Liptak, Bela G. *Instrumentation Processing in the Industries*. Philadelphia, PA: Chilton Book Company, 1973.

D. Potvin, John. *Applied Process Control Instrumentation*. Reston, VA: Reston Publishing Co., 198.

E. Tyson, Forrest. *Industrial Instrumentation*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1980.

INTERACTIVE LOOPS: BATCH PROCESSES
UNIT IX

INFORMATION SHEET

I. **Terms and definitions**

A. Batch process — A system where raw materials are controlled and mixed according to a ratio or a recipe in a timed sequence that produces a product at the end of a cycle, and the cycle is then repeated

B. Controller saturation — A condition where controller output reaches the maximum output point in either direction from setpoint, and stays there

C. Damper — A valve that does not close completely, and is used to modulate the flow of a gas or vapor

D. Overshoot — A condition where a process controller corrects an upset in a process, but continues on past the desired control point, and produces an error in the direction opposite the original error

E. PLC (programmagle logic controller) — A microprocessor based control system that can be programmed with simple instructions to run some process that operates in a step by step fashion to complete a sequential or partial sequential process

F. Reset windup — An error condition unique to proportional integral controllers that use an averaging process, and if a signal error exists for a long period, the controller will saturate (windup), hold the control output on long past the time needed to correct an error, and cause a large overshoot

G. Sequential control — A control strategy that mandates a fixed sequence of operations, usually timed to follow one after the other, but may be able to accept inputs that control decision points in a sequence rather than relying strictly on time-staged operations

H. Whirlpool — A brewing industry vessel that allows trub to settle out from wort immediately after brewing is completed

I. Trub — A mud-like material that separates from wort in a whirlpool and settles as sediment at the bottom of a whirlpool

J. Wort — A partially completed beer product that has been brewed, but then has to be fermented with yeast to become beer

II. **Fundamentals of batch processing**

A. In a continuous control process, the system is started, and continues to run until it is shut down for maintenance, repair, or design change.

INFORMATION SHEET

B. In a batch system, the process is started with every cycle, runs to completion, and then starts over again.

C. Batch processing is closely related to the flow process because many batch systems are designed to accept liquid products that flow into a batch vessel, are processed, and flow out again.

D. The major difference in batch control strategy is that the raw materials are brought into a vessel in accordance with a sequence or a set of proportions such as a recipe.

E. The materials are processed in response to changes in a set of variables such as heat and time, and follow a programmed procedure.

F. When one batch process is complete, the batch vessel is emptied, and the process is started over again.

III. Controlling batch processes

A. The batch process control strategy has unique problems, and the major problem is linked to getting the process started because batch systems have to restart the process after every cycle.

B. At the end of a batch, the product is emptied, and the process variables return to some rest point, such as:

1. Level drops to zero.
2. Temperature drops to ambient.
3. Pressure drops to atmospheric.

C. A batch process is usually started under conditions where the variables are far away from the desired operating points set by an operator.

D. If a batch process were to use PID control, it would experience a problem called reset windup, a condition where the integral mode causes complete saturation of the control output, and the batch product would be ruined.

E. In order to avoid PID control problems, PD can be used to avoid windup, or a sequential control form that activates the processing in a set order with time delays to avoid startup problems.

(NOTE: PD or sequential operation may still include PID at appropriate points in a total operation.)

INFORMATION SHEET

IV. **System overview** (Transparency 1)

A. Beer production has a series of batch processes linked by continuous flow operations which are typical of many beverage and food processing plants.

B. A good example of a batch system is the settling operation called a whirlpool which processes the wort used in making beer.

C. By examining a flow chart of a brewing process, one gets a better idea of how the wort whirlpool fits into the total scheme of beer making:

1. Barley comes into the headhouse where it is unloaded and stored.
2. Barley is transported and batched into steep tanks where malting begins.
3. The malt moves from storage to brewing.
4. In brewing, malt is mixed with other raw materials and water before going on to the brew kettle.
5. Wort is produced in the brew kettle, and sent through the hop jack to the whirlpool where the wort is settled and cooled.
6. After leaving the whirlpool, wort is quick-cooled, fermented, aged, blended, finished, and packaged for shipment.

D. Quality control is built into the total process, and the whirlpool batch system plays an important role in the finished product.

(NOTE: Detailed operation of the whirlpool batch system is covered in Handout #1.)

V. **Loop isolation for maintenance**

A. The isolation of loops in batch processes may or may not follow the same procedures used for continuous processes.

B. Since the batch process is started and controlled sequentially, the loop may not have the same degree of tight interaction that continuous processes have, so this may enable an operator to finish the batch and service the loop between runs.

C. When loops in batch processes cannot be maintained or serviced between runs, procedures for maintenance and service follow the guidelines for servicing any interactive loop.

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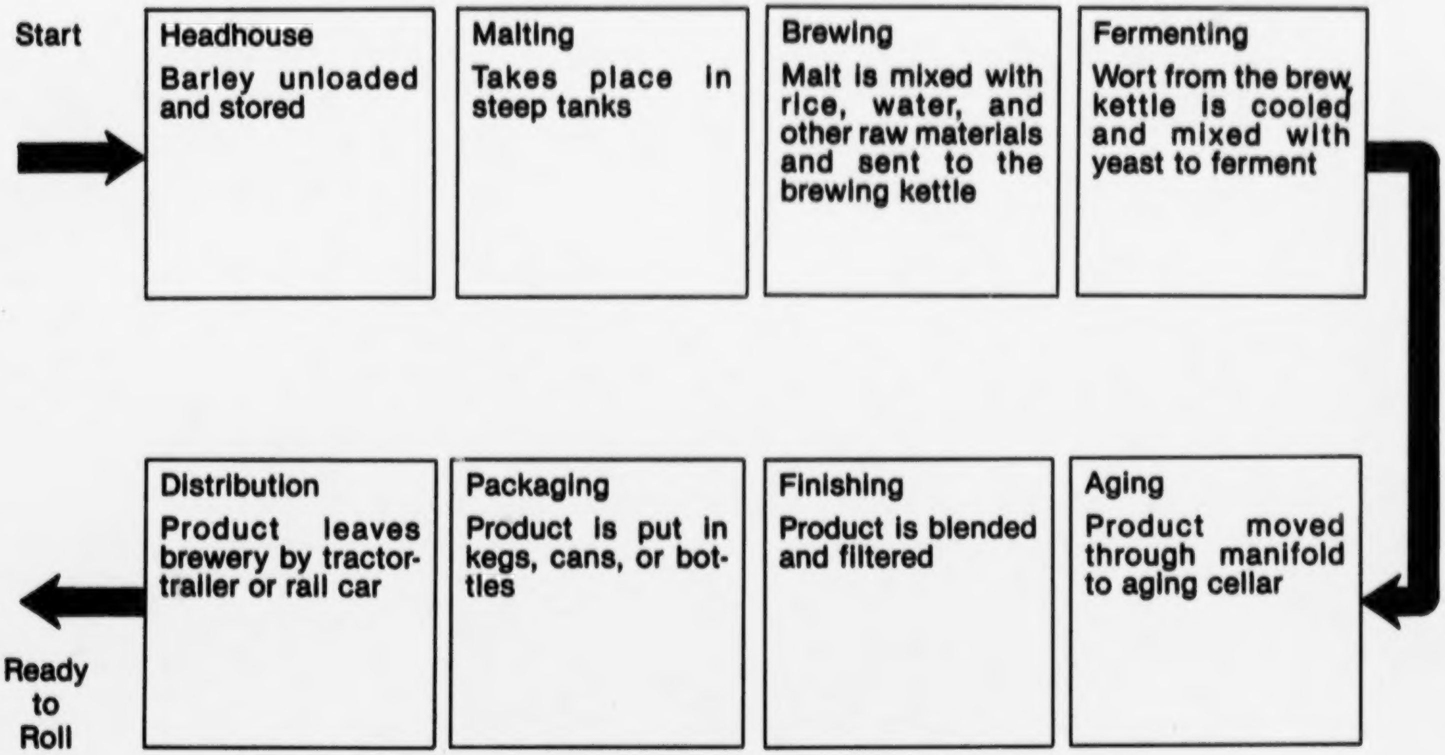
VI. Return to normal operations

A. In cases where an interactive batch loop cannot be serviced between batches, and if the loop had to be removed during the batch run, then in order to restore automatic operations, the loop that has been down should be put on line by reversing the plan used to take the loop off line.

B. First, the loop is brought on line manually, the interactive loops operating around it are switched to automatic in some critical order, and the new serviced loop is placed on line in order, and then switched to automatic.

Brewing Process Flow Chart



Start

Headhouse

Barley unloaded and stored

Malting

Takes place in steep tanks

Brewing

Malt is mixed with rice, water, and other raw materials and sent to the brewing kettle

Fermenting

Wort from the brew kettle is cooled and mixed with yeast to ferment

Aging

Product moved through manifold to aging cellar

Finishing

Product is blended and filtered

Packaging

Product is put in kegs, cans, or bottles

Distribution

Product leaves brewery by tractor-trailer or rail car

Ready to Roll

INTERACTIVE LOOPS: BATCH PROCESSES
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HANDOUT #1 — WHIRLPOOL BATCH SYSTEM

The whirlpool

The whirlpool is a 500 barrel (31.0 gal/bbl) settling pond that receives wort at approximately 90°C, and holds it for two hours, during which time the wort temperature drops to approximately 78°C. The name "settling pond" is used because a sediment called trub settles to the bottom of the whirlpool. After the wort goes on for fermentation, the trub is pumped out the bottom of the tank. In addition to temperature and level controllers, the whirlpool employs dampers and butterfly valves to facilitate a batch run (Figure #1 shows the operation).

Temperature and level controls

The batch is controlled by the interaction of level and temperature controllers. The whirlpool level is measured at the bottom of the tank by an electrical transducer marked TE1002, and transmitted by TT1002 to the controller. The liquid level is detected and transmitted by LLT1001 to the controller where the interaction of temperature, level, and time produces signals to fill the whirlpool from the manifold with LL1001 providing information for fill control.

Other batch control devices

The sterile air supply for the batch process is controlled by damper CD1020, and the vapor exhaust system is controlled by damper CD1017. Detergent hot water controlled by a series of solenoid operated butterfly valves CV1001, CV1002, CV1012, and CV1015 make up a CIP (Clean-in-Place) system, which is powered by Pump Motor 1003, and controlled by CV1005, CV1016, and CV1006.

Completing the batch process

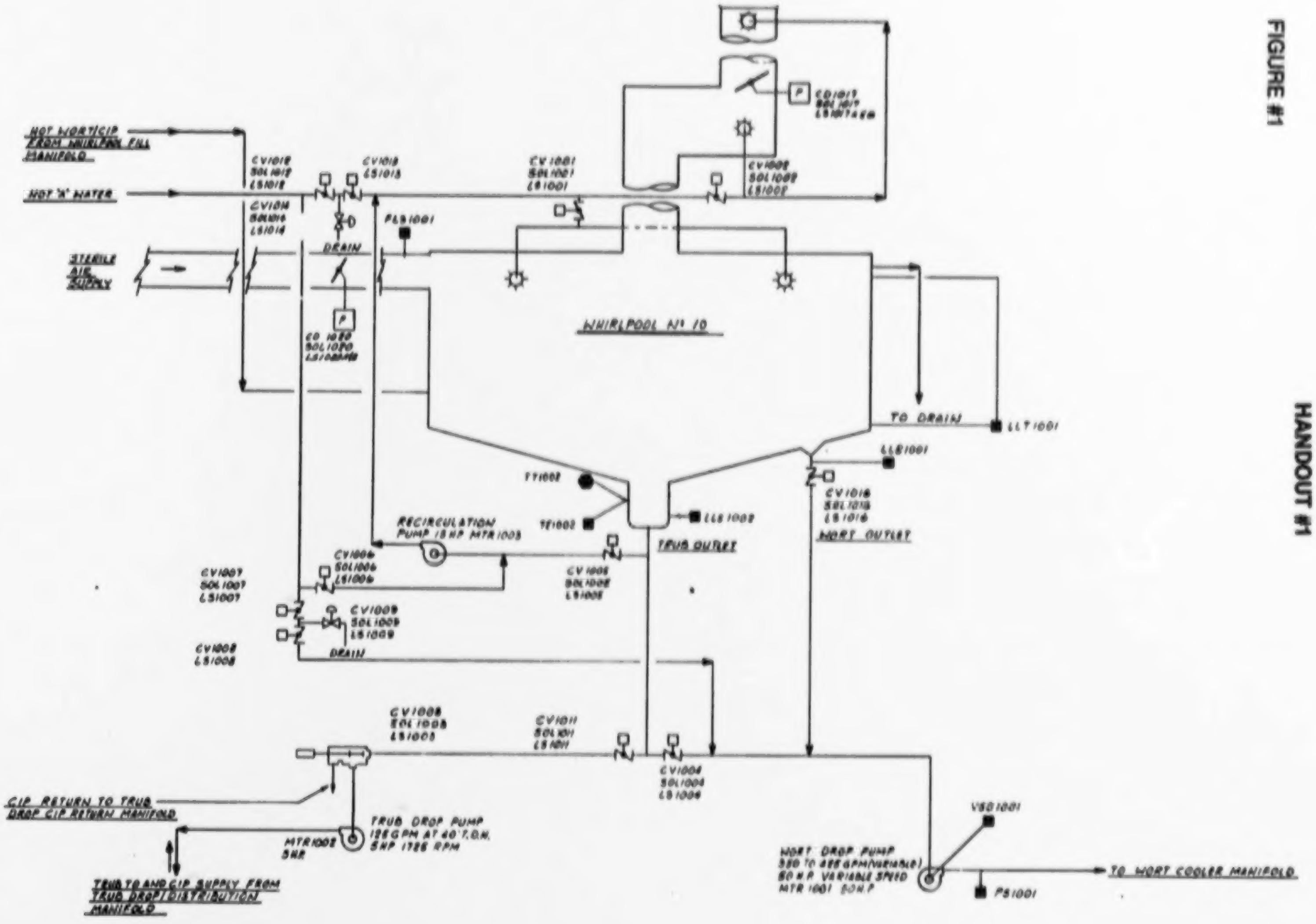
After two hours with the temperature at approximately 78°C, the wort is drained via solenoid valve C1015 while the level is monitored by LLS1001. When the wort has been cleared from the whirlpool, the trub is drained out the bottom of the tank, and monitored by LLS1002 until the tank is emptied. The whirlpool tank is then cleaned by the hot water (CIP) spray system, and made ready for refilling with a fresh supply of wort.

Conclusions

In many beverage and food processing operations, batch processes solve critical process problems. The whirlpool settling pond promotes product quality through a sterile cooling and sedimentation cycle.

FIGURE #1

HANDOUT #1


HOT WORT/CIP FROM WHIRLPOOL FILL MANIFOLD
HOT 'A' WATER
STERILE AIR SUPPLY
CV1012 SOL1012 LS1012
CV1014 SOL1014 LS1014
CV1013 LS1013
DRAIN
CD 1020 SOL1020 LS1020A&B
FLS1001
CV1001 SOL1001 LS1001
CV1002 SOL1002 LS1002
CD1017 SOL1017 LS1017A&B
P
WHIRLPOOL Nº 10
TO DRAIN
LLT1001
LLS1001
TT1002
TE1002
LLS1002
CV1016 SOL1016 LS1016
WORT OUTLET
TRUB OUTLET
RECIRCULATION PUMP 15HP MTR1003
CV1006 SOL1006 LS1006
CV1005 SOL1005 LS1005
CV1007 SOL1007 LS1007
CV1009 SOL1009 LS1009
CV1008 LS1008
DRAIN
CV1003 SOL1003 LS1003
CV1011 SOL1011 LS1011
CV1004 SOL1004 LS1004
CIP RETURN TO TRUB DROP CIP RETURN MANIFOLD
TRUB DROP PUMP 125GPM AT 40' T.D.H. 5HP 1725 RPM
MTR1002 5HP
TRUB TO AND CIP SUPPLY FROM TRUB DROP DISTRIBUTION MANIFOLD
VSD1001
WORT DROP PUMP 350 TO 455 GPM(VARIABLE) 50 H.P. VARIABLE SPEED MTR 1001 50H.P.
PS1001
TO WORT COOLER MANIFOLD

INTERACTIVE LOOPS: BATCH PROCESSES
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ASSIGNMENT SHEET #1 — IDENTIFY CONTROL FUNCTIONS IN A BATCH PROCESS

Directions: Refer to Handout #1 and Figure 1 of the handout to answer the following questions about interactive loops in batch processes.

1. In a whirlpool batch system, the whirlpool is called a settling pond. Why the name settling pond?

   Answer: ______________________________

   ____

   ____

2. What elements interact to provide signals to fill the whirlpool?

   Answer: ______________________________

   ____

3. What is meant by a CIP system? What does the CIP system accomplish, and how does it accomplish its objective?

   Answer: ______________________________

   ____

   ____

4. What two things does the sterile air supply accomplish in a whirlpool batch system?

   Answer: ______________________________

   ____

   ____

5. What happens to wort that enters a whirlpool at 90° C, and how long does the process take?

   Answer: ______________________________

   ____

ASSIGNMENT SHEET #1

6. How does the whirlpool batch system display the difference between batch processes and other types of industrial control systems?

Answer: ____

____

____

____

INTERACTIVE LOOPS: BATCH PROCESSES
UNIT IX

ANSWERS TO ASSIGNMENT SHEET

1. Because a sediment called trub settles out of the whirlpool.
2. Temperature, level, and time
3. CIP means Clean in Place. The CIP system cleans the whirlpool after each batch run, and it cleans with a supply of detergent hot water.
4. The air supply cools the wort and promotes product quality.
5. The wort is cooled to 78° C over a period of two hours.
6. Other systems run continuously, but the whirlpool batch is cleaned at the end of each run and the cycle starts over.

INTERACTIVE LOOPS: BATCH PROCESSES
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TEST

NAME ______________________________ SCORE ______________

1. Match the terms on the right with their correct definitions.

_____a. A system where raw materials are controlled and mixed according to a ratio or a recipe in a timed sequence that produces a product at the end of a cycle, and the cycle is then repeated

_____b. A condition where controller output reaches the maximum output point in either direction from setpoint, and stays there

_____c. A valve that does not close completely, and is used to modulate the flow of a gas or vapor

_____d. A condition where a process controller corrects an upset in a process, but continues on past the desired control point, and produces an error in the direction opposite the original error

_____e. A microprocessor based control system that can be programmed with simple instructions to run some process that operates in a step by step fashion to complete a sequential or partial sequential process

_____f. An error condition unique to proportional integral controllers that use an averaging process, and if a signal error exists for a long period, the controller will saturate, hold the control output on long past the time needed to correct an error, and cause a large overshoot

_____g. A control strategy that mandates a fixed sequence of operations, usually timed to follow one after the other, but may be able to accept inputs that control decision points in a sequence rather than relying strictly on time-staged operations

1. Damper
2. Reset windup
3. Trub
4. Wort
5. Batch process
6. Overshoot
7. Whirlpool
8. PLC
9. Controller saturation
10. Sequential control

TEST

_____h. A mud-like material that separates from wort in a whirlpool and settles as sediment at the bottom of a whirlpool

_____i. A brewing industry vessel that allows trub to settle out from wort immediately after brewing is completed

_____j. A partially completed beer product that has been brewed, but then has to be fermented with yeast to become beer

2. Select true statements concerning fundamentals of batch processing by placing an "X" beside each statement that is true.

_____a. In a continuous control process, the system is started, and continues to run until it is shut down for maintenance, repair, or design change.

_____b. In a batch system, the process is started with every cycle, runs to completion, and then starts over again.

_____c. Batch processing is closely related to the flow process because many batch systems are designed to accept liquid products that flow into a batch vessel, are processed, and flow out again.

_____d. The major difference in batch control strategy is that the raw materials are brought into a vessel in accordance with a sequence or a set of proportions such as a recipe.

_____e. The materials are processed in response to changes in a set of variables such as heat and time, and follow a programmed procedure.

_____f. When one batch process is complete, the batch vessel is emptied, and the process is started over again.

3. Solve problems concerning controlling batch processes by selecting the correct answer to each of the following questions.

a. A problem unique to batch processing is what, getting the batch stopped or getting the batch started?

Answer: ____

b. If a batch process were to use PID control, it would experience a problem called reset windup which would result in what, an overshoot that would ruin the product or an undershoot that would ruin the product?

Answer: ____

TEST

4. Select true statements concerning system overview by placing an "X" beside each statement that is true.

   (NOTE: For a statement to be true, all parts of the statement must be true.)

   _____a. Beer production has a series of batch processes linked by continuous flow operations which are quite different from other beverage and food processing.

   _____b. A good example of a batch system is the settling operation called a whirlpool which processes the wort used in making beer.

   _____c. By examining a flow chart of a brewing process, one gets a better idea of how the wort whirlpool fits into the total scheme of beer making:

   1) Barley comes into the headhouse where it is unloaded and stored.

   2) Barley is transported and batched into steep tanks where malting begins.

   3) The malt moves from storage to brewing.

   4) In brewing, malt is mixed with other raw materials and water before going on to the brew kettle.

   5) Wort is produced in the brew kettle, and sent through the hop jack to the whirlpool where the wort is settled and cooled.

   6) After leaving the whirlpool, wort is quick-cooled, fermented, aged, blended, finished, and packaged for shipment.

   _____d. Quality control is built into the total process, and the whirlpool batch system plays an important role in the finished product.

5. Solve problems concerning loop isolation for maintenance by selecting the correct answer to each of the following questions.

   a. The isolation of loops in batch processes when compared to continuous processes may what, follow a completely different procedure or may or may not follow the same procedure?

   Answer: ____

   b. Because of the nature of batch processes, servicing a loop must affords what service opportunity, to service the loop after the batch starts or to service the loop between batches?

   Answer: ____

TEST

6. Complete statements concerning return to normal operations by circling the material that best completes each statement.

   a. In cases where an interactive batch loop cannot be serviced between batches, and if the loop had to be removed during the batch run, then in order to restore automatic operations, the loop that has been down should be put on line by **(reversing the plan used to take the loop off line, first manual then automatic mode)**.

   b. First, the loop is brought on line **(manually, automatically)**, the interactive loops operating around it are switched to automatic in some critical order, and the new serviced loop is placed on line in order, and then **(switched to, left in)** automatic.

(NOTE: If the following activity has not been accomplished prior to the test, ask your instructor when it should be completed.)

7. Identify components and their functions in a typical batch loop process. (Assignment Sheet #1)

INTERACTIVE LOOPS: BATCH PROCESSES
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ANSWERS TO TEST

1.

a.	5	f.	2
b.	9	g.	10
c.	1	h.	3
d.	6	i.	7
e.	8	j.	4

2. a, b, c, d, e, f

3. a. Getting the batch started
   b. An overshoot that would ruin the product

4. b, c, d

5. a. May or may not follow the same procedure
   b. To service the loop between batches

6. a. Reversing the plan to take the loop off line
   b. Manually, switched to

7. Evaluated to the instructor's satisfaction